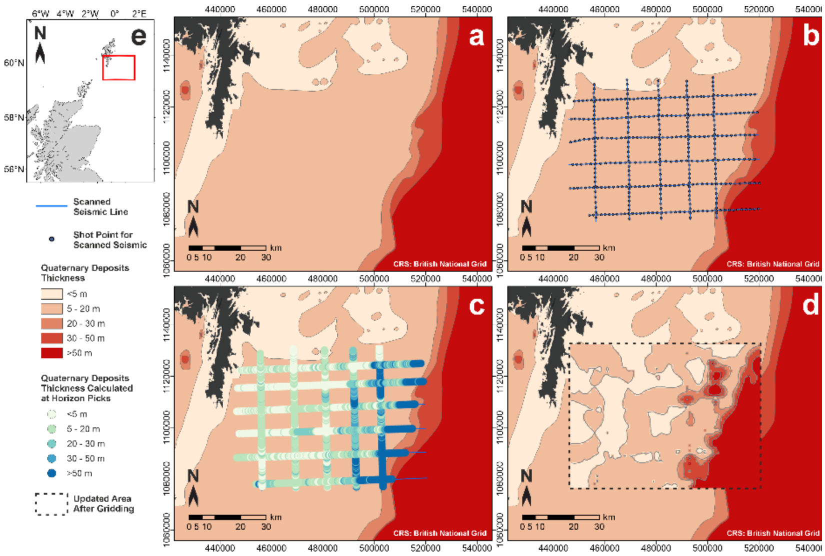
Extracting Geological Geospatial Information from UK Continental Shelf Scanned Legacy Seismic Data

Marine Geoscience Programme

Open Report OR/25/036



BRITISH GEOLOGICAL SURVEY

MARINE GEOSCIENCE PROGRAMME

OPEN REPORT OR/25/036

Extracting Geological Geospatial Information from UK Continental Shelf Scanned Legacy Seismic Data

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Keywords

Legacy Seismic; Scanned Paper Seismic Records; ArcGIS; Spatial Reference; Quaternary Thickness .

Front Cover

Example use of the workflow outlined within the report to demonstrate value for updating existing offshore geological maps. Contains an extract from existing Quaternary thickness geological factor map produced as part of collaboration between BGS and The Crown Estate in 2014. BGS © UKRI. Contains OS data © Crown copyright and database right 2025.

Bibliographical reference

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The Lyell Centre, Edinburgh, British Geological Survey 2025

Foreword

This report has been prepared by the British Geological Survey (BGS), as a set of instructions to provide assistance with the extraction of useful geospatial data from the wealth of publicly available scanned legacy seismic data that can be accessed via the BGS Offshore Geoindex.

Contents

Summary

This report provides a detailed workflow to extract spatially referenced lithostratigraphic information from scanned seismic and borehole records curated by the British Geological Survey.

The rationale for this report is to enable any technical staff proficient in, and with access to, ArcGIS Pro, and some form of drawing software e.g., CorelDraw, to make digital picks of geological information from the wealth of legacy data and therefore maximise outputs.

The instructions contained within the report are written in such a way that they can be used by, for example, undergraduate university students enrolled in geoscience programs. Therefore, this report could be used to underpin undergraduate and postgraduate research projects looking to utilise open-source data, which would be mutually beneficial for the strategic goals of BGS to improve existing maps of the shallow geology on the UK continental shelf (UKCS).

The workflow assumes that the user starts with no data but has access to the required software. Detailed instructions are provided to direct the user to the relevant data sources and how to download and import the data into their working areas.

Users following the workflow, would progress from data access, through download and data preparation, geospatial referencing of scanned (originally paper-based-datasets), to ultimately producing digital X,Y,Z data points for interpreted geological horizons. The ouput X,Y,Z data points can used to generated gridded surfaces or be imported into a GIS program or subsurface data visualisation program, where they can be used to aid, or complement, interpretations picked on modern digital SEGY-format seismic data.

Introduction

The National Geological Data Centre hosted at the British Geological Survey (BGS) curates a wealth of scanned seismic data that was acquired during the mid-late 20th century. These data are publicly available and can be accessed through the BGS Offshore Geoindex.

The Offshore Geoindex also hosts shapefiles for the geographical positions of the scanned seismic data and the coordinates of shot points used during the acquisition. Using these shapefiles in combination with the image files, the images can be spatially referenced in GIS software. The spatial reference assigned to the scanned images can be quality checked against open-source bathymetry data from the Admiralty Marine Data Portal, where the scans and existing bathymetry are coincident. The combination of these elements provides a method through which geological information in the subsurface can be digitised, the details of which is outlined in the workflow section of this report.

Workflow

This report will demonstrate the workflow steps using example data from the Moray Firth, in north-eastern Scotland.

1 CREATE A PROJECT SPACE

Most of the workflow requires a GIS software package, and the outlined steps in this report use ArcGIS Pro. Before getting started, you should create a project space where the datasets should be downloaded/collated, and the GIS project set up.

1.1 You may want to create the project space on a local drive to your PC, so that the large datasets will load quickly (back up the project later to a network drive).

Inside your project space, create a folder for the GIS project e.g., ‘Scanned_Seismic_GIS’, a ‘Datasets’ folder, within which create a folder for ‘Scanned_Seismic’ and ‘Bathymetry’. For example, the directory structure would look like:

```
C:\local\Scanned_Seismic_Project
    |--Datasets
    |    |--Scanned_Seismic
    |    |--Bathymetry
    |--Scanned_Seismic_GIS
```

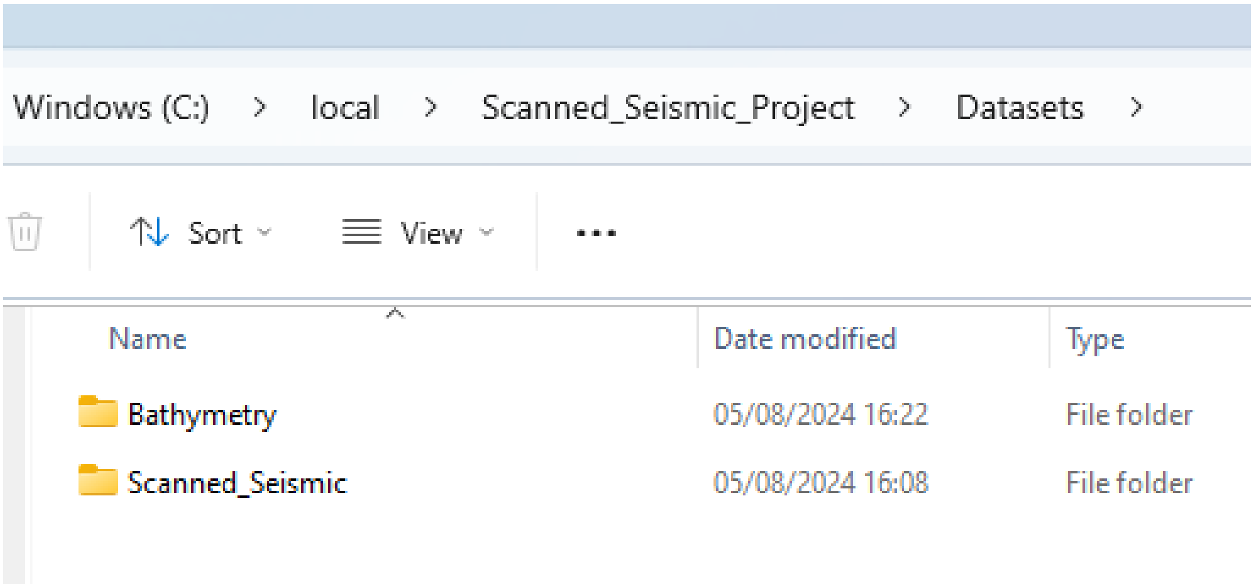


Figure 1.1

2 DOWLOAD DATA AND SET UP ARCGIS PRO PROJECT

To ensure the best possible accuracy to the results of the process detailed in this report, you should endeavour to use scanned seismic data that is coincident with high-resolution bathymetry data.

The two platforms from which to retrieve necessary datasets are:

- The BGS Offshore Geoindex (https://www.bgs.ac.uk/map-viewers/geoindex-offshore/)
- The Admiralty Marine Data Portal (https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal)

2.1 Go to the offshore Geoindex and scroll down to and click on the ‘Open BGS Geoindex (offshore) button.

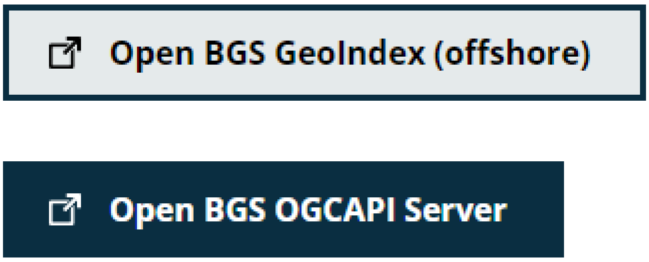


Figure 2.1.

2.2 You are confronted with a page that looks like this:

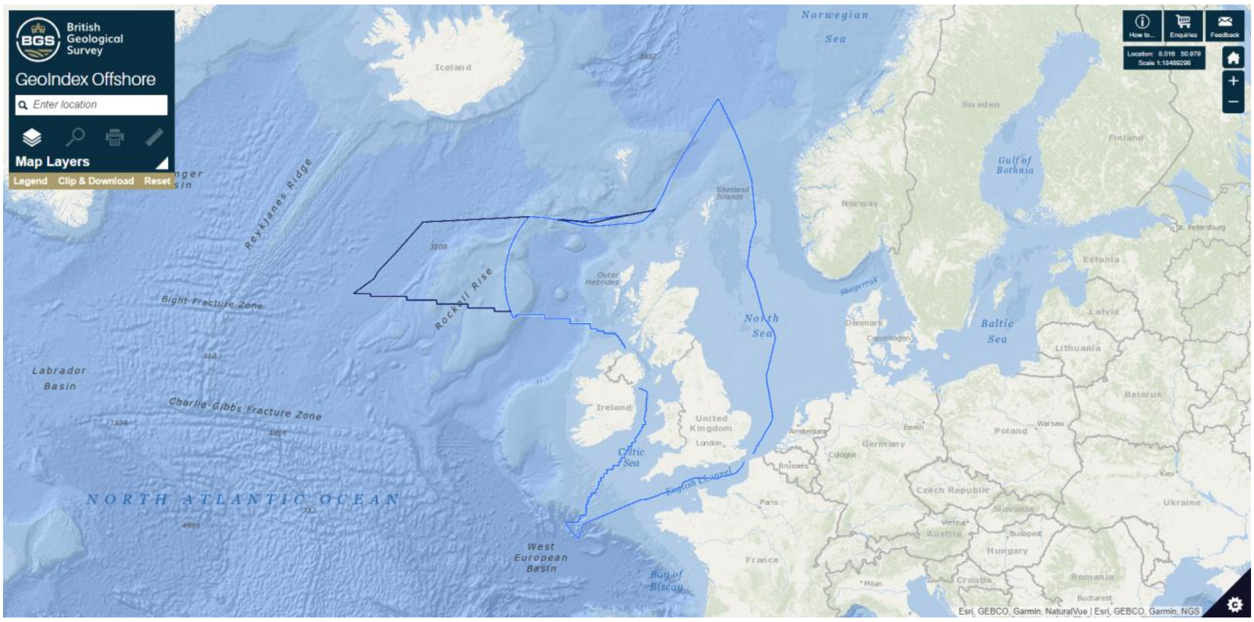


Figure 2.2. Basemap sources: Esri, GEBCO, Garmin, NaturalVue | Esri, GEBCO, Garmin, NGS

2.3 Click on the arrow next to ‘Map Layers’ to expand the map Geoindex contents list.

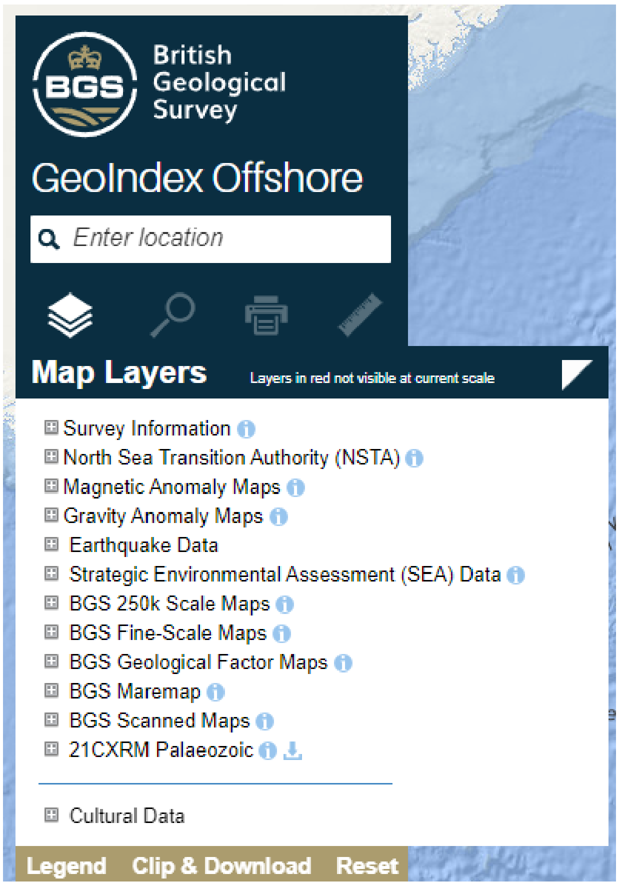


Figure 2.3

2.4 Click on the + next to Survey Information to expand the layers. Then select the tick boxes next to ‘Shot Points’ and ‘Seismic Reflection’.

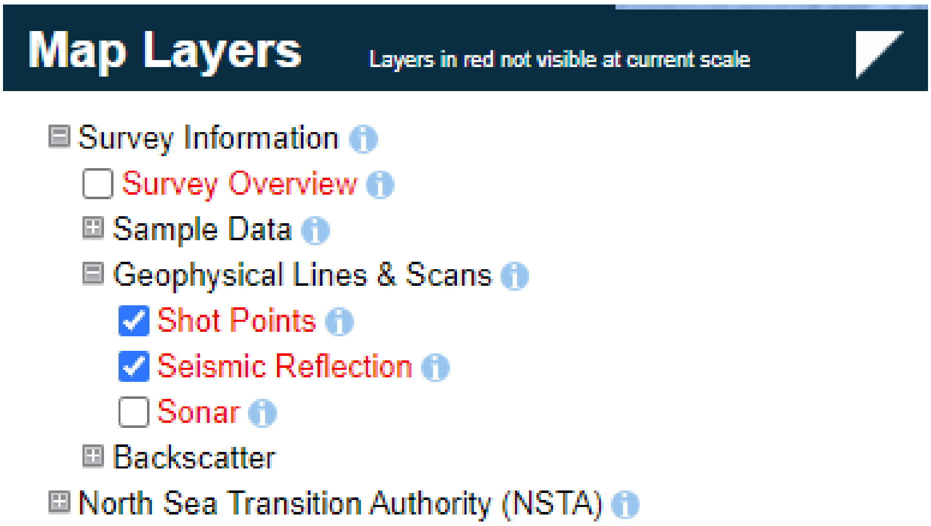


Figure 2.4

2.5 Zoom in on the map by using the mouse scroll or controls at the top right until you see these datasets appear.

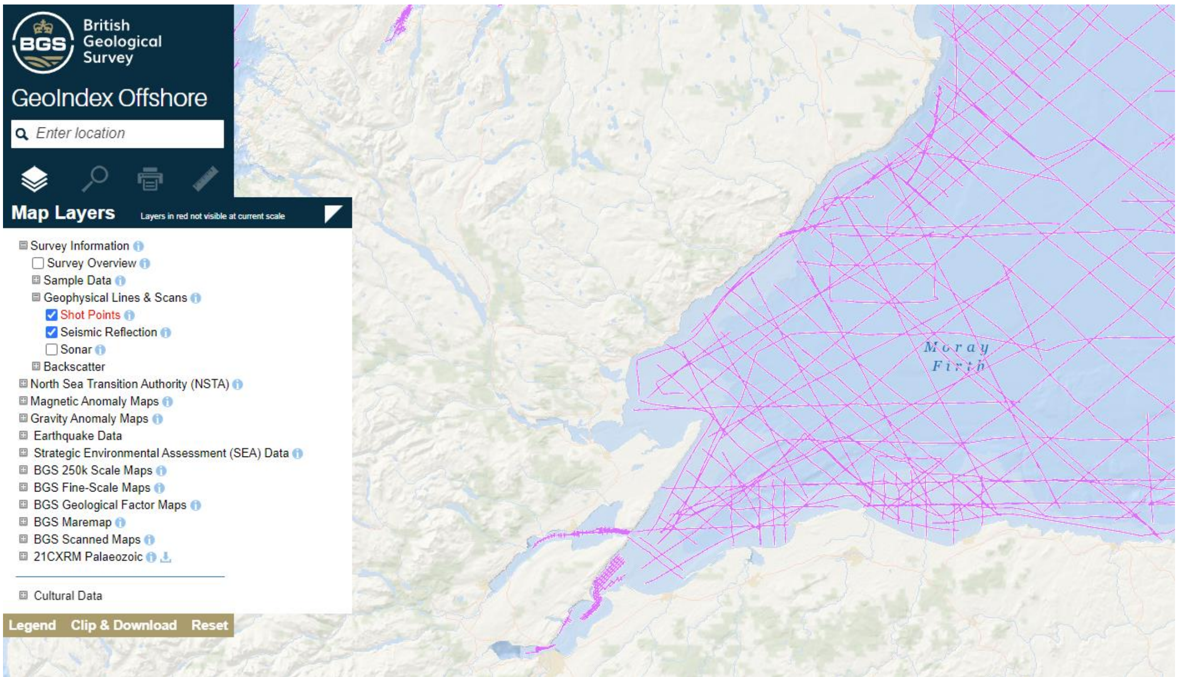


Figure 2.5. Basemap sources: Esri, GEBCO, Garmin, NaturalVue | Esri, GEBCO, Garmin, NGS

2.6 Centre your map on your particular region of interest, then click on 'Clip & Download' at the base of the 'Map Layers' panel.

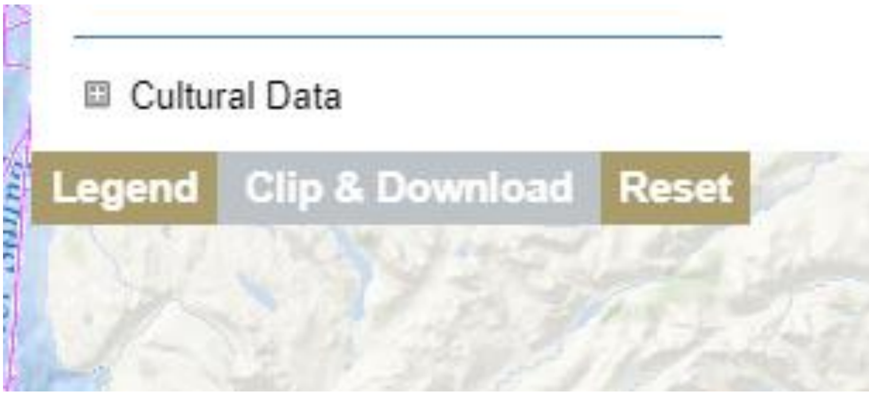


Figure 2.6

2.7 A dialogue box will have appeared, click on 'Draw AOI'. You should also be able to move the dialogue box out of the way by clicking on the dark-blue top ribbon and dragging it.

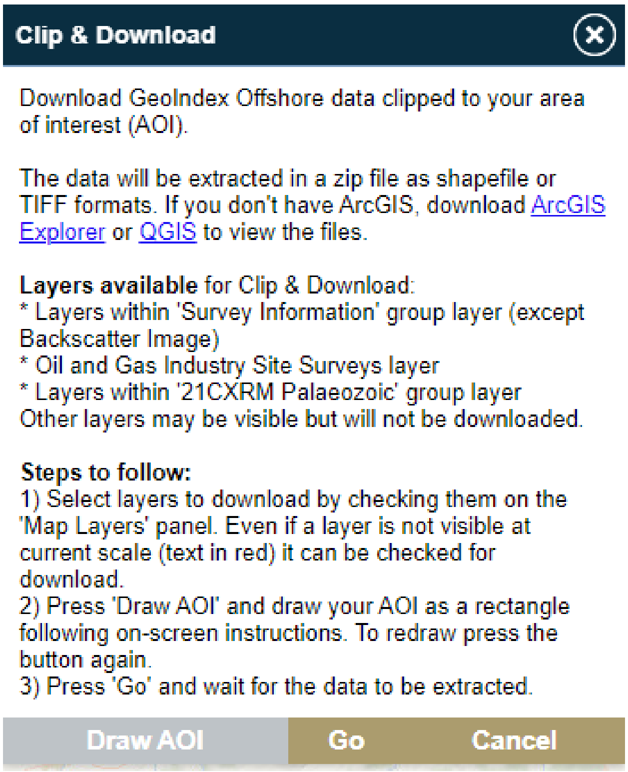


Figure 2.7

2.8 Draw a rectangle over the area of interest by holding down the left-hand mouse button and dragging. You may want to select a larger area than depicted in the image below, to ensure you get sufficient coverage that includes the start and ends of seismic lines you want to work on.

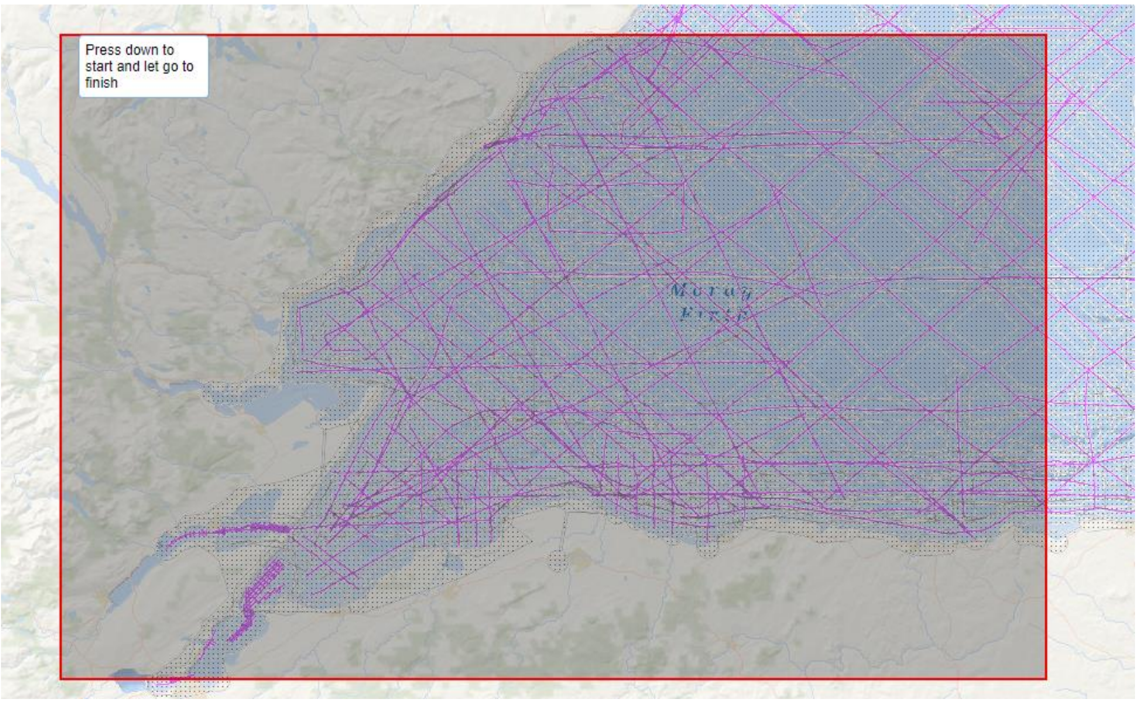


Figure 2.8. Basemap sources: Esri, GEBCO, Garmin, NaturalVue | Esri, GEBCO, Garmin, NGS

2.9 Once happy with the selection, click on 'Go' at the bottom of the dialogue box.

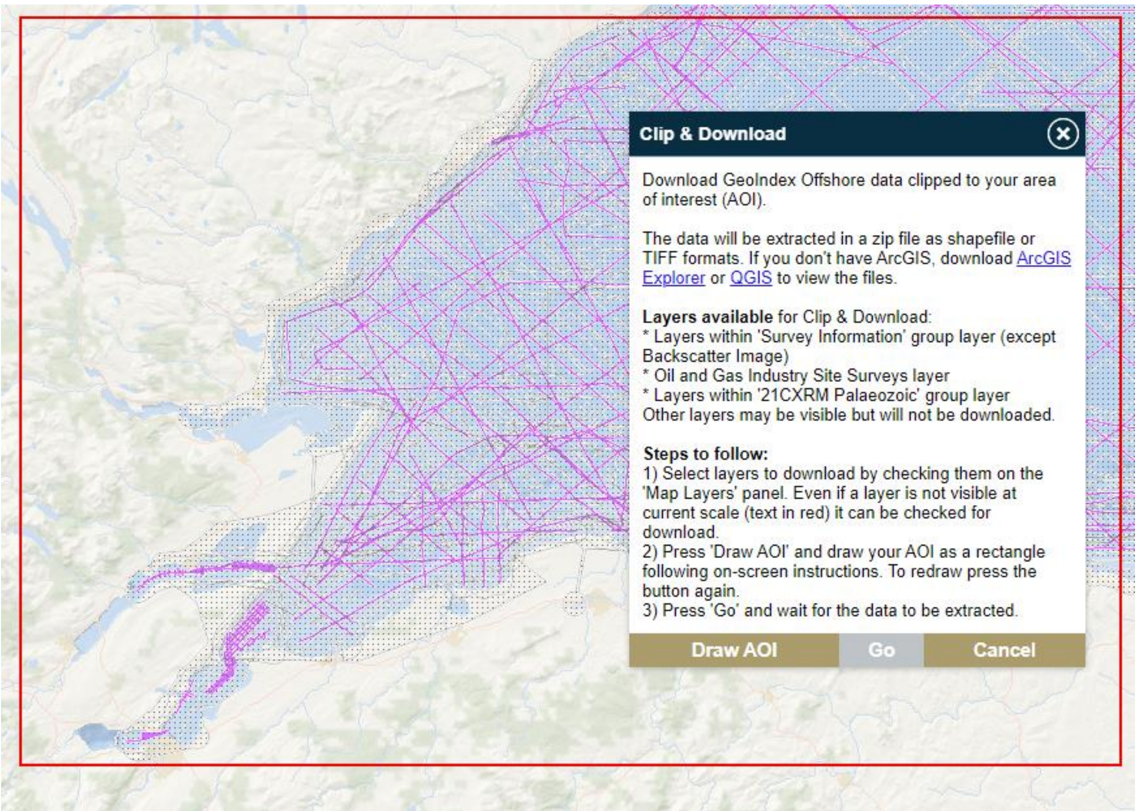


Figure 2.9. Basemap sources: Esri, GEBCO, Garmin, NaturalVue | Esri, GEBCO, Garmin, NGS

2.10 The platform will take a few moments to clip and download the data, once complete you will get the following message:

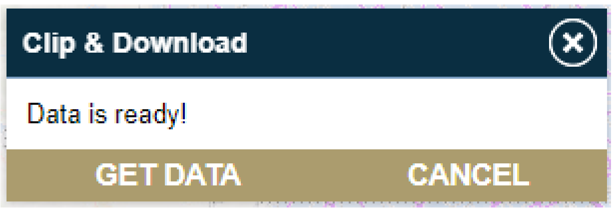


Figure 2.10

2.11 Click on 'Get Data',and save the data to your C:\local\Scanned_Seismic_Project\Datasets\Scanned_Seismic folder. The data will have downloaded in a zipped folder.

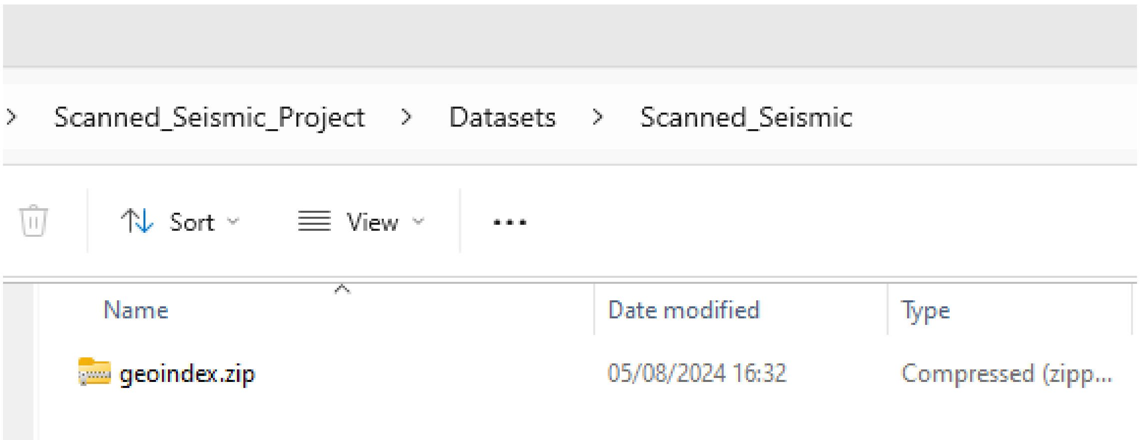


Figure 2.11

2.12 Extract the contents to the 'Scanned_Seismic' folder (delete 'geoindex' in the path before pressing 'Extract' to avoid generating duplicate folders).

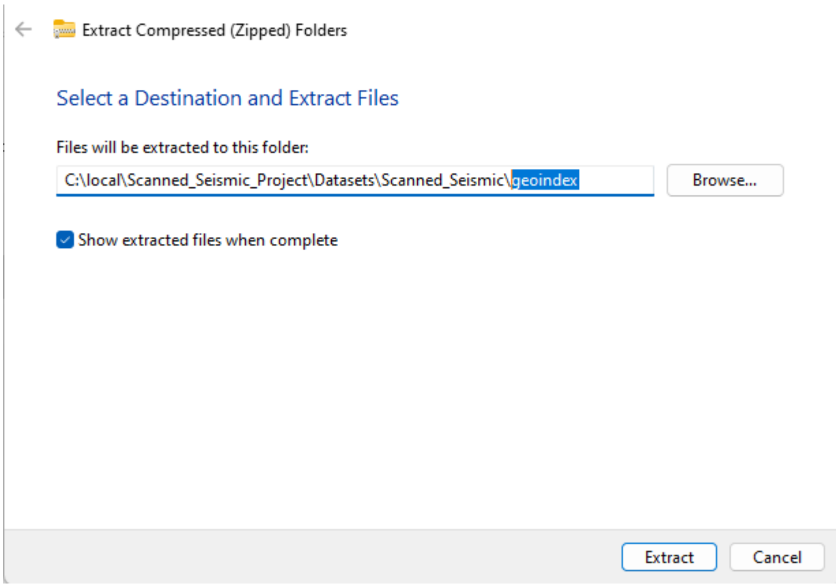


Figure 2.12

2.13 The relevant files are stored within a subfolder called 'zipfolder'. Open the folder and move the files within one directory up so that they appear in the 'Scanned_Seismic' folder. You should see files for 'Seismic_Reflection' and 'Shot_Points'. Delete the 'zipfolder' and 'geoindex.zip' folders.

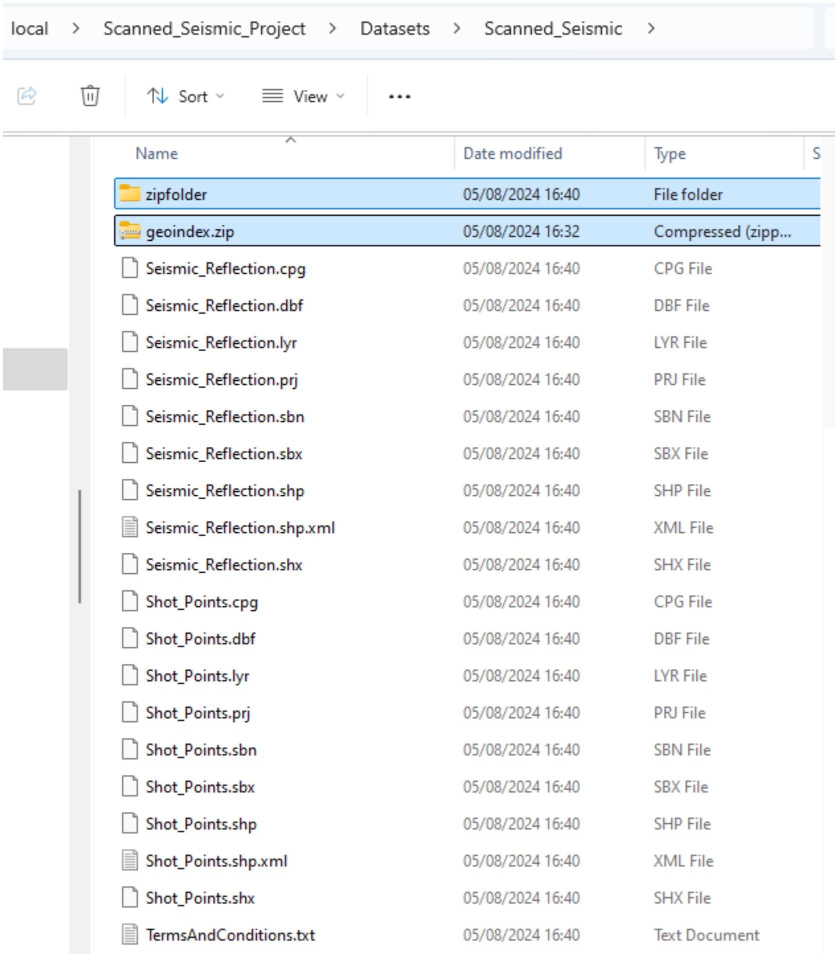


Figure 2.13

2.14 Before downloading the bathymetry data, the next step is to create a GIS project. Open ArcGIS Pro, choose 'Map' under 'New Project' and when the 'New Project' dialogue box appears, deselect the checkbox next to 'Create a folder for this project', then click on the folder icon next to location to select your C:\local\Scanned_Seismic_Project\Scanned_Seismic_GIS folder. Give the Project a suitable name e.g., 'Scanned_Seismic_Maps', click ok.

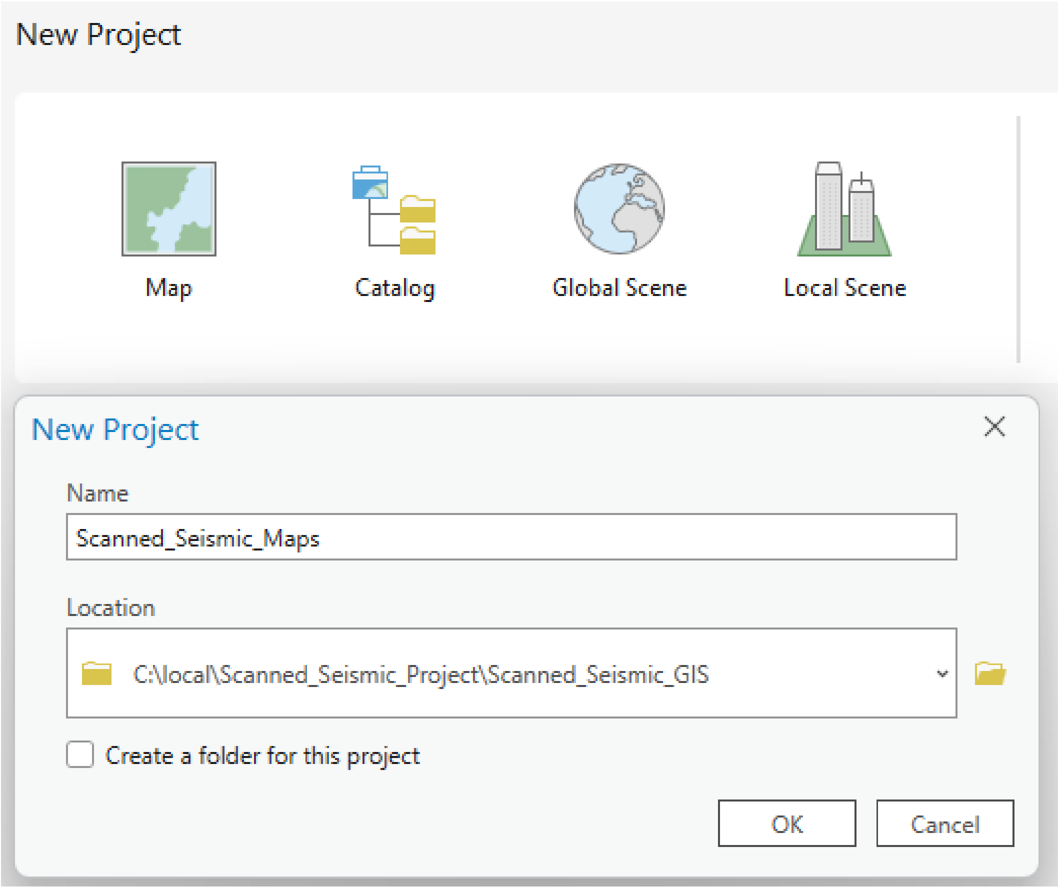


Figure 2.14

2.15 Change the name of the default map to 'Reference_Map'.

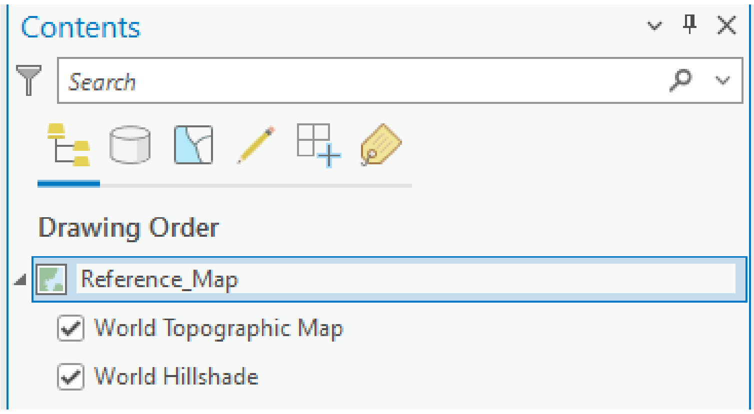


Figure 2.15

2.16 Right-click on the map in the table of contents and select ‘Properties’.

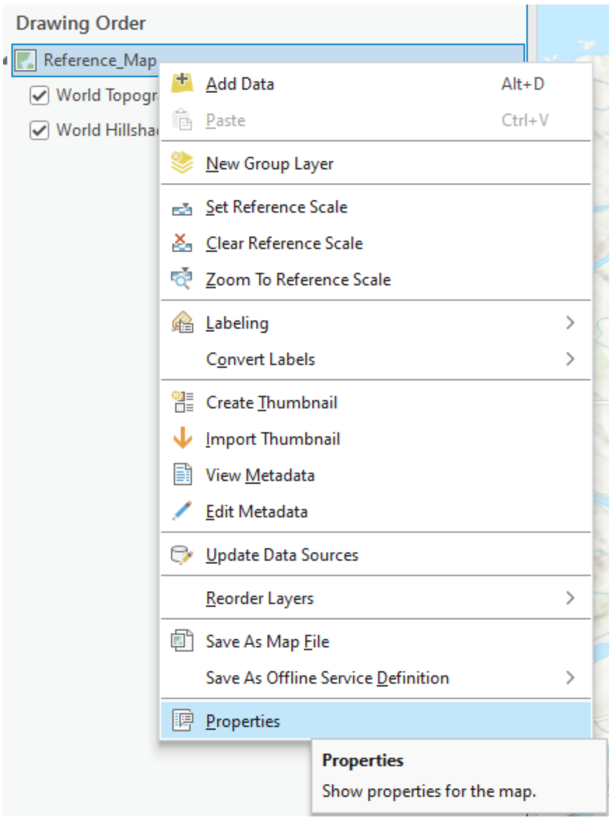


Figure 2.16

2.17 Select the ‘Coordinate Systems’ tab, then find and select ‘British National Grid’ from ‘Projected Coordinate Systems > National Grids > United Kingdom’ (also add this CRS to your favourites), and click OK.

Figure 2.17

2.18 Open the Catalog pane, and right click on ‘Folders’ and select ‘Add Folder Connection’, choose your ‘Datasets’ folder and click OK. Your Datasets folder should now appear in the Catalog (you may need to right-click > Refresh).

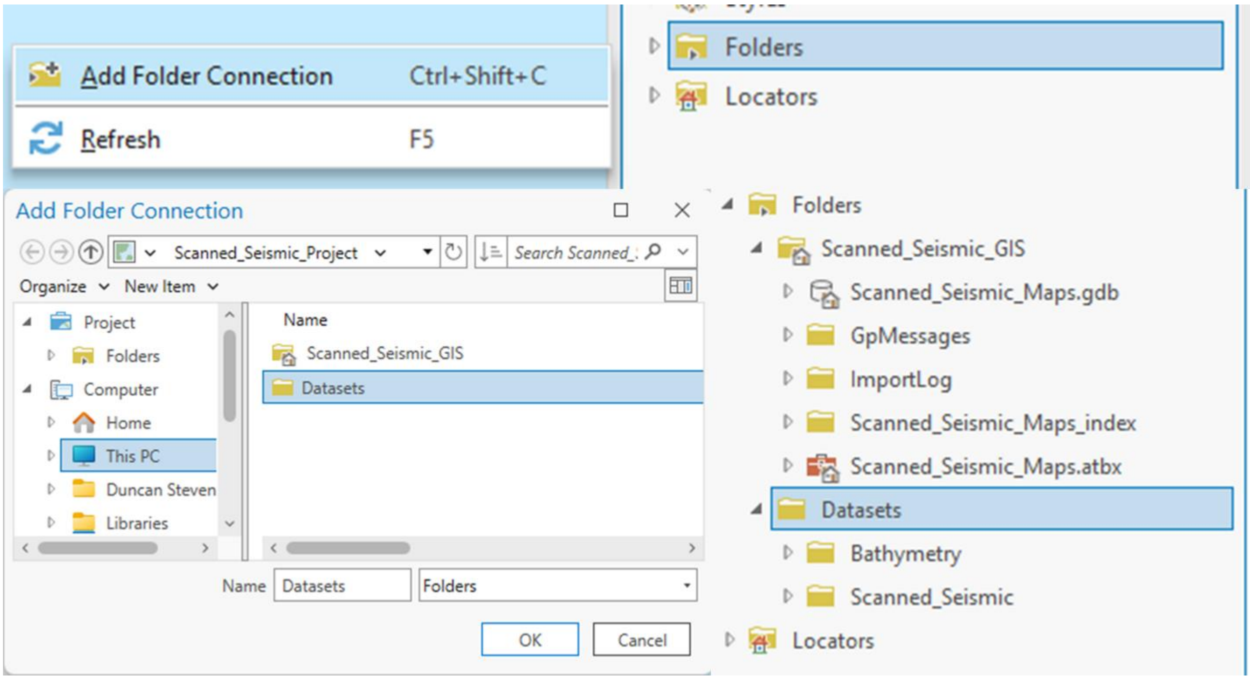


Figure 2.18

2.19 Expand ‘Scanned_Seismic’ to see the shapefiles that were downloaded.

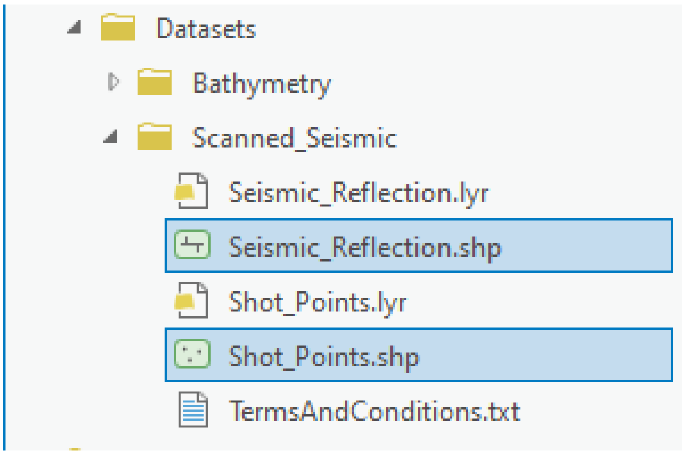


Figure 2.19

2.20 Select the Seismic_Reflection and Shot_Points .shp files and drag and drop them into the map. In the Drawing Order, move Shot_Points above Seismic_Reflection.

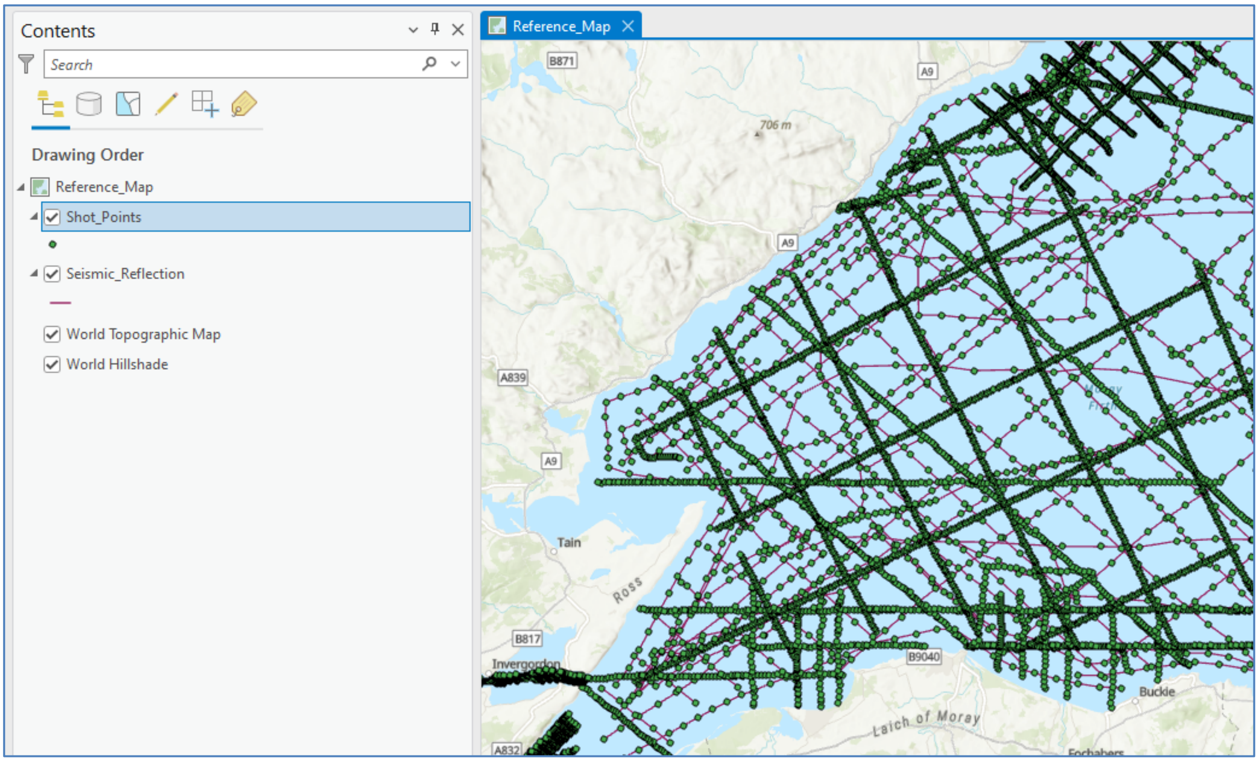


Figure 2.20

2.21 The next step is to download coincident UK Hydrographic Office Civil Hydrography Programme bathymetry data from the Admiralty Marine Data Portal (https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal).

Scroll down on the webpage to click on 'Discover' under 'Seabed Mapping Services'.

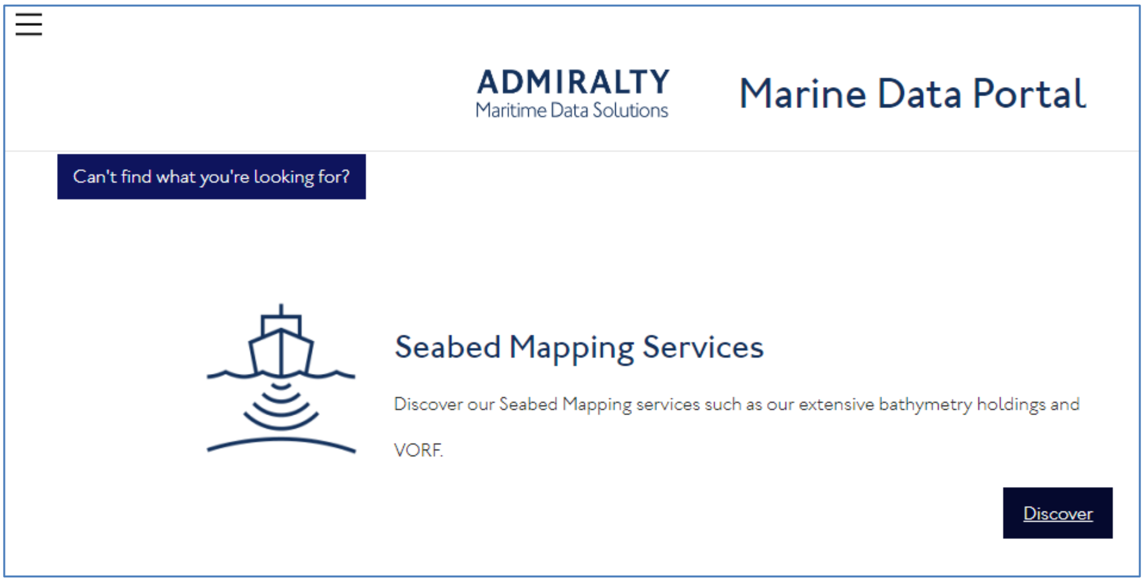


Figure 2.21. © Crown Copyright 2020 UK Hydrographic Office

2.22 Scroll down on the next page and click on ‘Try the new service’ under ‘Beta Seabed Mapping Data Service’

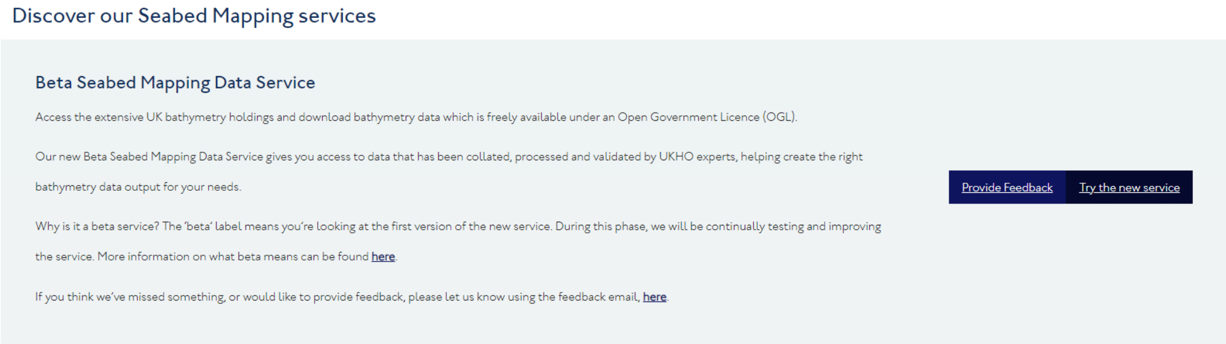


Figure 2.22. © Crown Copyright 2020 UK Hydrographic Office

2.23 Once the Seabed Mapping Service has opened, zoom in on your area of interest. Select either the ‘Select features by drawing a custom polygon’ or ‘Select features by drawing a rectangle’. Draw around your area of interest by clicking once and dragging (if an error message saying your selected area exceeds 1000 km^2, just reduce the size of the polygon/rectangle – the relevant datasets should still be selected). The datasets within your selection will appear in a panel on the right, tick the checkboxes next to the relevant datasets to your work. Click Next.

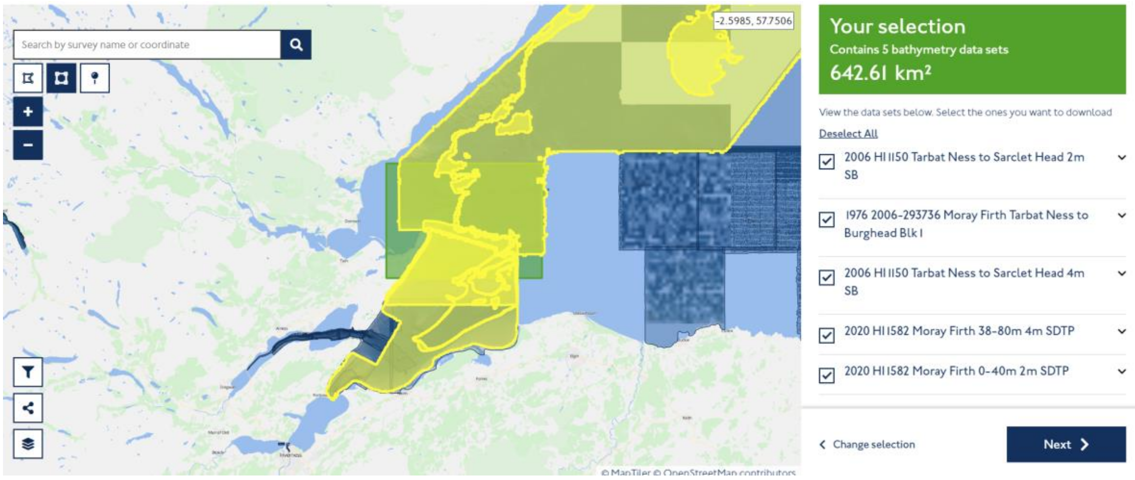


Figure 2.23. © Crown Copyright 2020 UK Hydrographic Office. Basemap sources: © MapTiler © OpenStreetMap contributors

2.24 Agree to the Terms of Use and click Download, you will need to enter your email and login or create a free account.

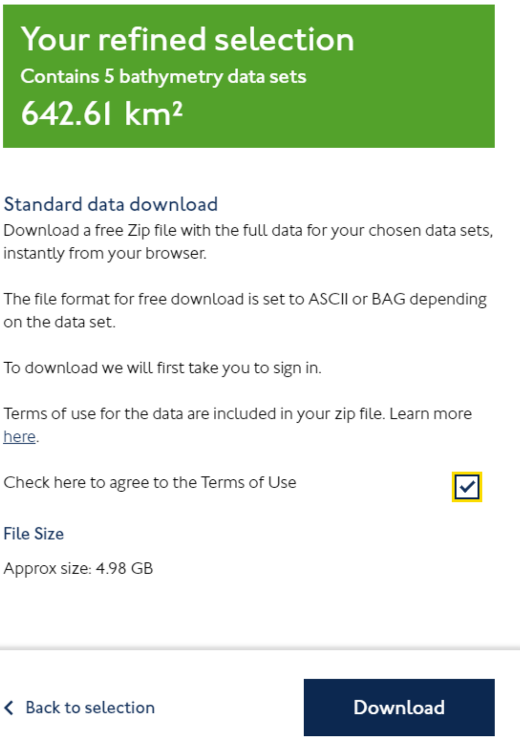


Figure 2.24. © Crown Copyright 2020 UK Hydrographic Office

2.25 The data will be downloaded in a zipped folder. Extract the contents into your C:\local\Scanned_Seismic_Project\Datasets\Bathymetry folder.

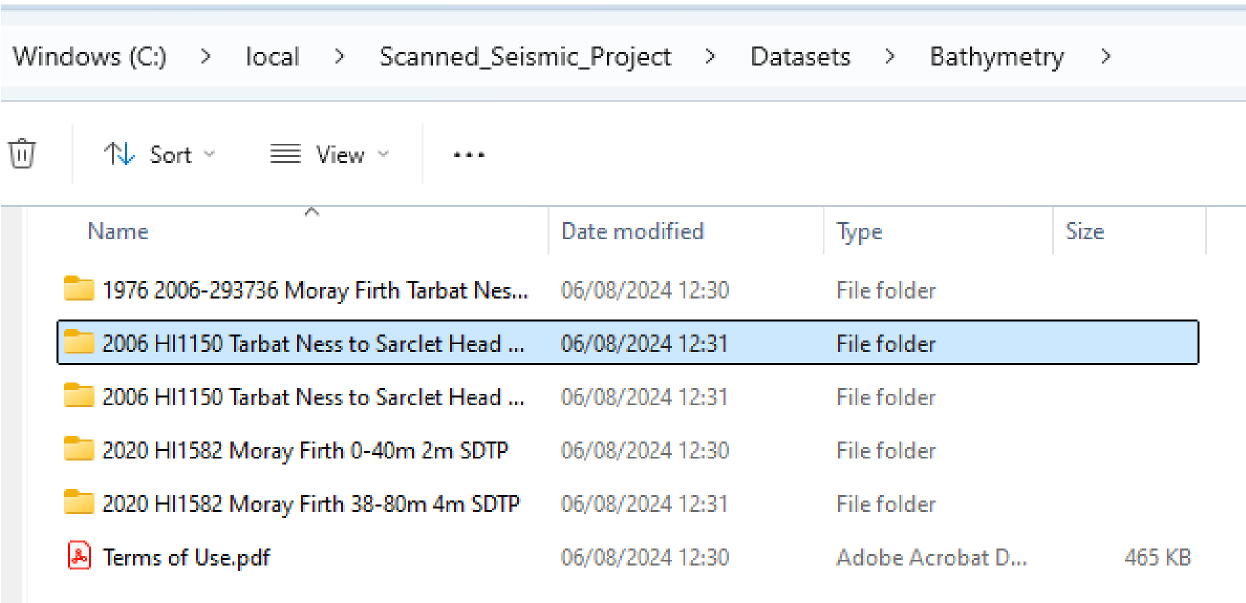


Figure 2.25

2.26 Inside the folders that have been extracted, you will see a series of files, and another zipped folder. The useful files here are the BAG file(s).

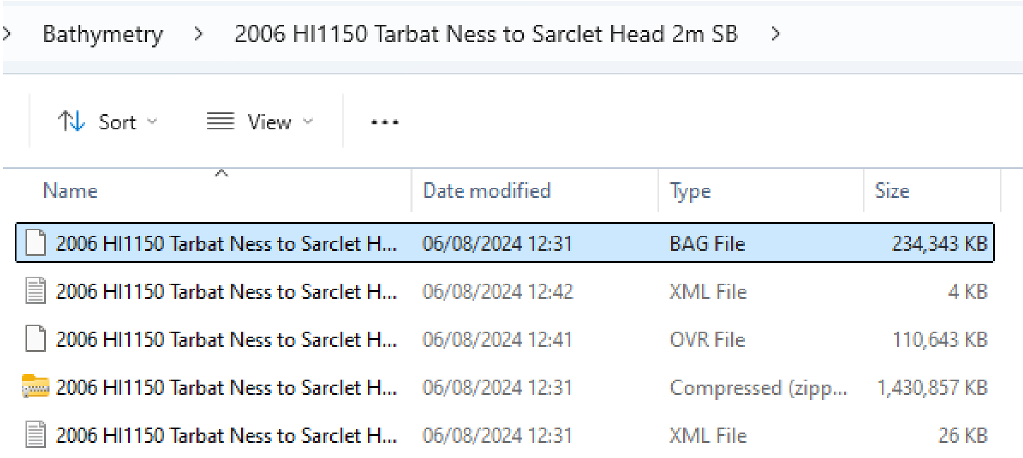


Figure 2.26

2.27 In your GIS project, in the Catalog pane, you should see the downloaded folders and files within the tree. The BAG files will appear as rasters. Expand one of the rasters to see the different bands – generally they will have an 'elevation' band and an 'uncertainty' band. Drag and drop an elevation band into your map. When asked to Build pyramids, leave the defaults (checkbox next to 'Build' under Pyramids is selected) and click OK.

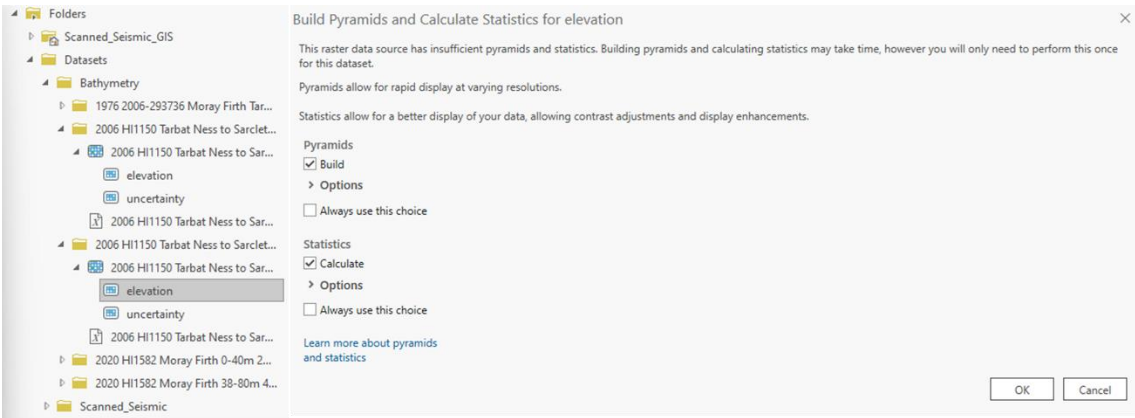


Figure 2.27

2.28 Add as many of the elevation rasters as you require to your map in the same way. The vertical datum for the UKHO bathymetry is metres below lowest astronomical tide (mLAT).

2.29 You may want to create a seamless bathymetry dataset over your area of interest by combining multiple rasters. To do this, go to the Analysis tab, open Tools, and in the Geoprocessing pane that appears, use the search bar to search for 'Mosaic to new raster'.

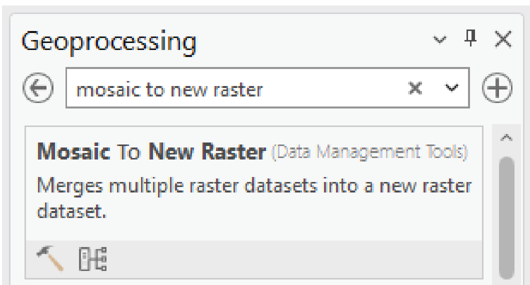


Figure 2.28

2.30 Select the rasters you have in your map (the elevation bands) as the input rasters, select your C:\local\Scanned_Seismic_Project\Datasets\Bathymetry folder as the Output Location, give a name that is less than 13 characters long, choose the relevant UTM zone as the Spatial Reference (the same coordinate reference system as the original bathymetry downloads), change the Pixel type to '16 bit unsigned', input a suitable cellsize that is similar to the original downloaded bathymetry, input 1 as the number of bands, set the Mosaic Operator and Mosaic Colormap Mode to 'First'. Everything else can be left as the defaults. Run.

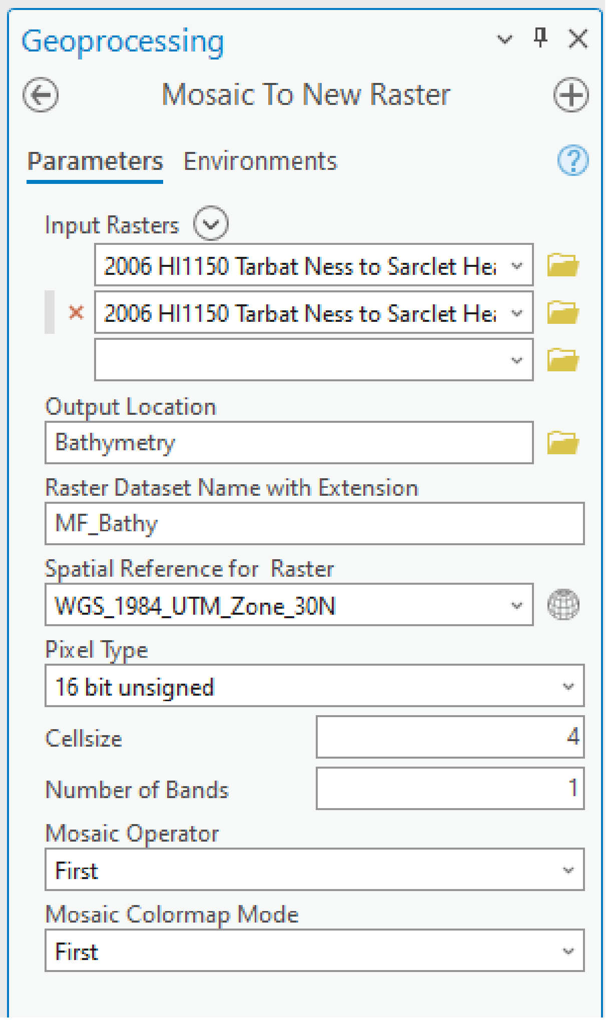


Figure 2.29

2.31 The new raster should have appeared in the table of contents if the process completed correctly. If so, remove the originally downloaded bathymetry rasters from your map by right-clicking on them in the table of contents and selecting 'remove', so you are left with the mosaic. Change the name of the layer for the merged bathymetry in the table of contents to add the suffix 'mLAT'.

2.32 The next step is to generate a bathymetry dataset that is plotted in two-way-travel time from the merged bathymetry raster, so it can be compared directly with the scanned seismic data. To do this, you need to perform a depth to time conversion. In Analysis > Tools search for ‘Raster Calculator’.

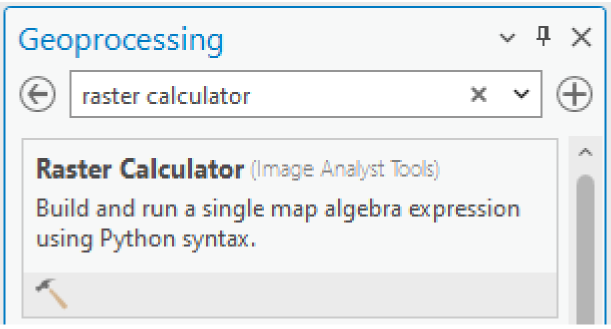


Figure 2.30

2.33 Use the Raster Calculator tool to create an expression that will convert the bathymetry values to two-way-travel time ((2 × Raster) ÷ water velocity in metres per second). Use an appropriate value for the velocity. In this example 1490 m/s is used. Give the output raster an appropriate name i.e., the same as the name you gave the merged depth bathymetry, but with the suffix ‘TWT’, this time use the default output location (which will be the project’s geodatabase, but check the raster can be exported later) – you may also want to add the velocity value you used to the name if you have enough character space (at the very least, make a note of the velocity you used). Go to the ‘Environments’ tab and select the same UTM zone coordinate system you have been using for the bathymetry as the Output Coordinate System. Under ‘Extent’ click on the second icon and select the input raster (the top/left/right/bottom coordinates will then be filled out automatically). Select the input raster under ‘Cell Size’ and select ‘Preserve Resolution’ under Cell Size Projection Method, and select the input raster under ‘Sanp Raster’.

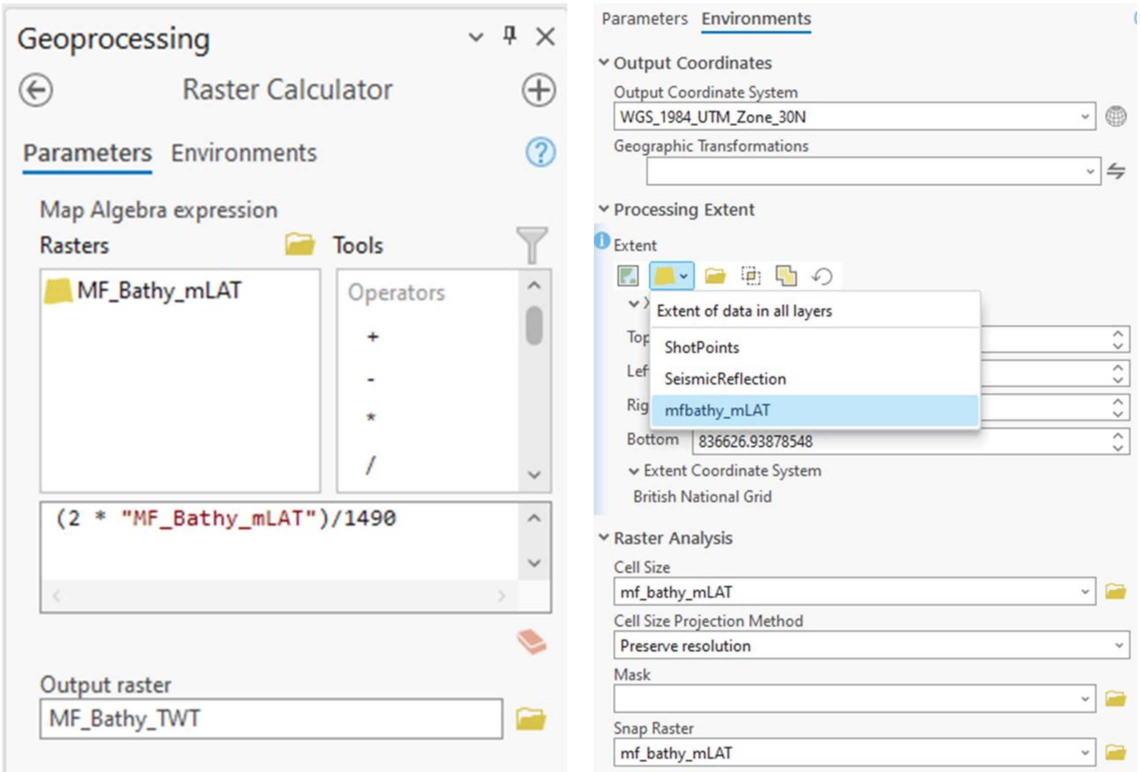


Figure 2.31

2.34 You may find that it is worth exporting the raster from the project geodatabase to your Bathymetry folder, so that it can be shared, or more easily imported into other projects. Right-click on the newly created raster in the table of contents and go to Data > Export Raster. Select the appropriate output location folder (your Bathymetry folder), and you should be able to leave most other fields as the defaults (you can leave the format as TIFF). You may want to ensure that the cell size fields are integer values if they have included a lot of decimals (e.g., 4 and 4). Click 'Export'.

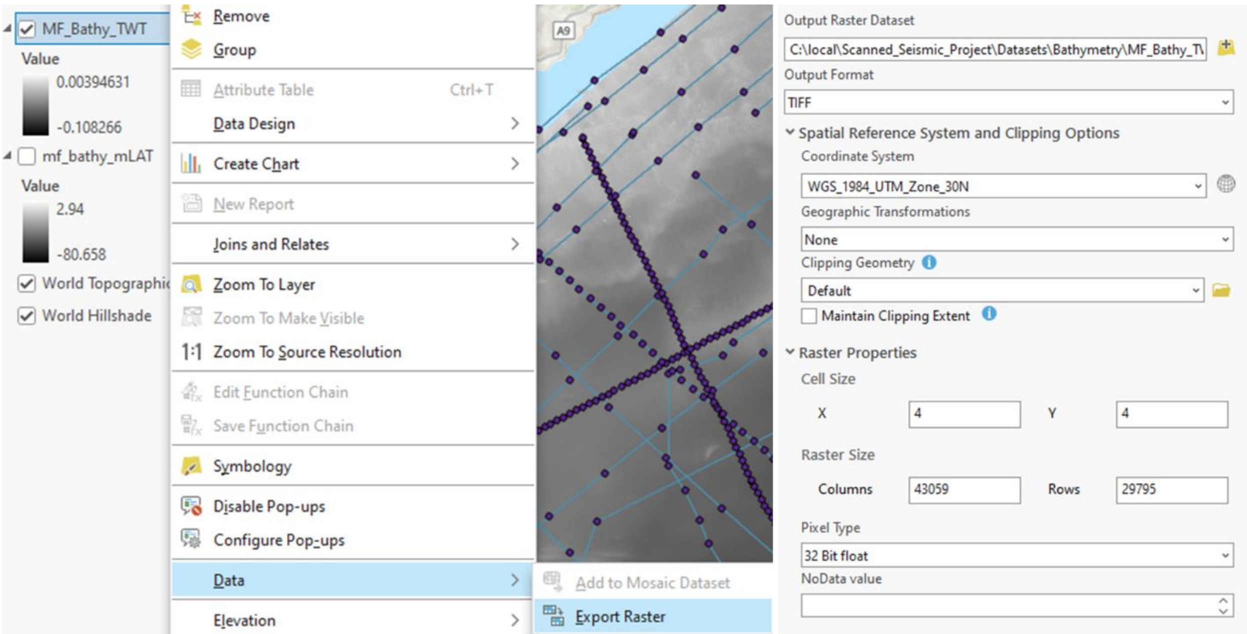


Figure 2.32

2.35 The exported raster will probably have been automatically added to your map, you may want to remove the one from the geodatabase from the map, leaving only one.

2.36 If the exported layer has a white background obscuring other elements of your map, right-click on the raster in the table of contents and open the Symbology panel. In the Symbology panel, go to the 'Mask' tab, and tick the checkbox next to 'Display background value'. Ensure that 'No color' is selected as the fill. The background value is probably 0, which is entered by default in the value field, so the background should have disappeared, if not, you will have to look at the histogram for the raster dataset to work out which pixel value is the background value (where there is an unrealistic spike).

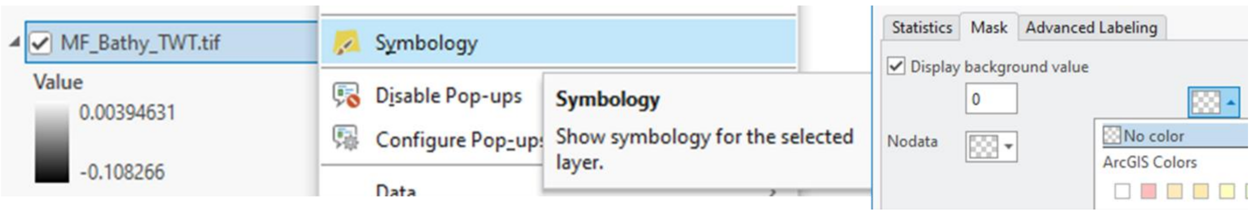


Figure 2.33

Now you have a reference map within an ArcGIS Pro project to work from. Save and back up. The next stage is to assess which of the legacy seismic data is workable, prepare the chosen scanned image(s) for import into ArcGIS, and then make an interpretation.

3 SELECT SCANNED LEGACY SEISMIC DATA

Within your GIS project, look at which seismic lines you may want to use by assessing their location relative to the bathymetry – lines which are coincident with bathymetry over most of their length will be easier to work with, but that doesn't mean they will be particularly useful scans if the seismic data is very noisy.

Shortlisting which seismic lines are usable in terms of feasibility of geological interpretation may take some time and will rely largely on brief visual inspection of the scanned data. You may want to involve a colleague(s) to help you assess whether a scan can be interpreted for your purpose. Ideally, you would include as many of the scans as possible within your region of interest.

3.1 To assess the scan, you'll need to identity one you'd like to query, use the 'Explore' tool to left-click on the line (one of the line features in the 'Seismic_Reflection' layer/shapefile) to bring up its attributes. You will see "CRUISE_LIN" make a note of this for the line(s) you want to work with. For example, the line shown below is 1970/3#52.

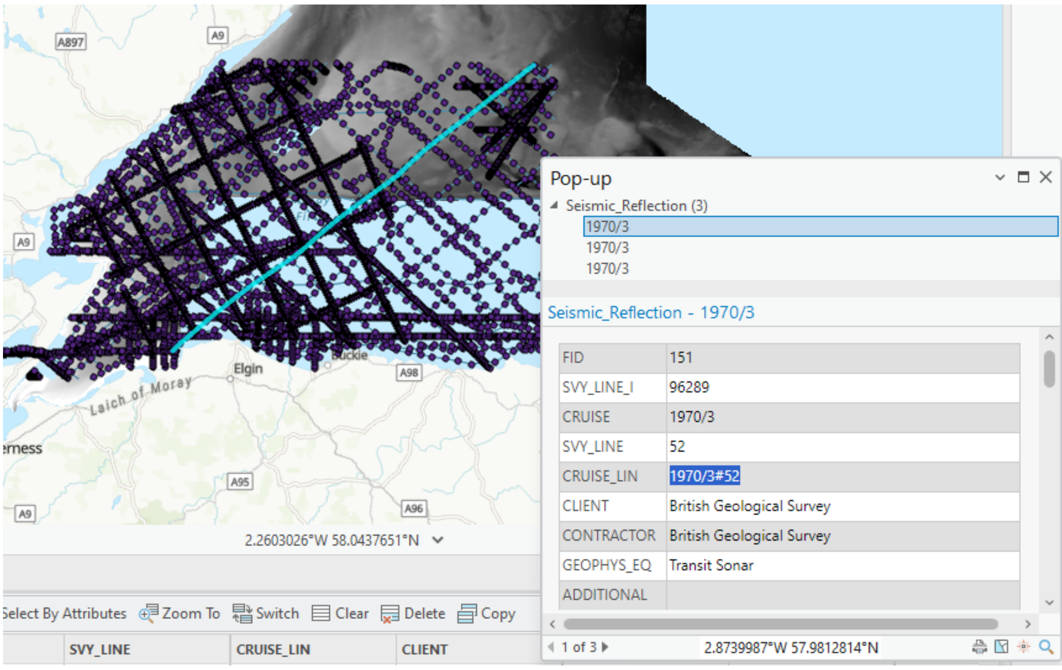


Figure 3.1

3.2 Each line may have multiple seismic data types associated with it. In the example above, though only one line was selected, the Pop-up shows 'Seismic_Reflection (3)', so there are 3 different elements detected at the same line location. The one that is currently selected is the 'Transit Sonar' line, which is shown in the 'GEOPHYS_EQ' field.

3.3 In the Pop-up, look at which data are associated with the line location. You may be interested in different data types depending on your specific goal. For the example in this report, we are interested in the 'Sparker' data. Select the identified data which has 'Sparker' in the 'GEOPHYS_EQ' attribute field.

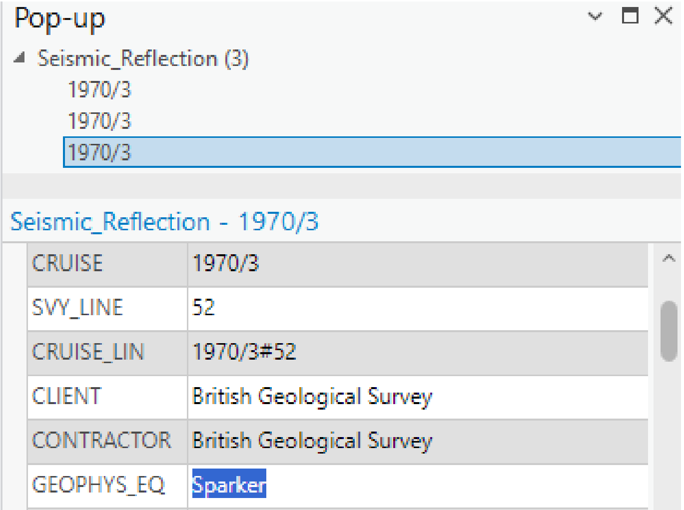


Figure 3.2

3.4 Scroll down in the Pop-up to the 'SCAN_URL' attribute field, where there will be a hyperlink to where the scanned seismic data is stored online. Click on the link, which will open the scan viewer in your default web browser.

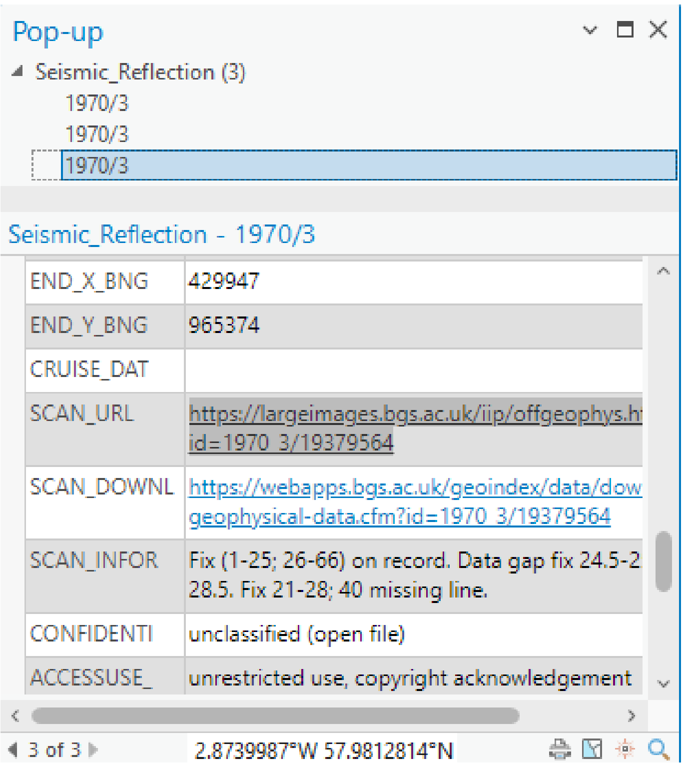


Figure 3.3

3.5 The page that opens will look something like the example below. Here you can zoom in and out, scroll around the image and make your own visual assessment of the data to determine if you will be able to extract any useful interpretations from it based on the image quality. Don't worry if there are 'steps' in the scan where it doesn't line up along the length – you will be able to work around this by splitting the image.

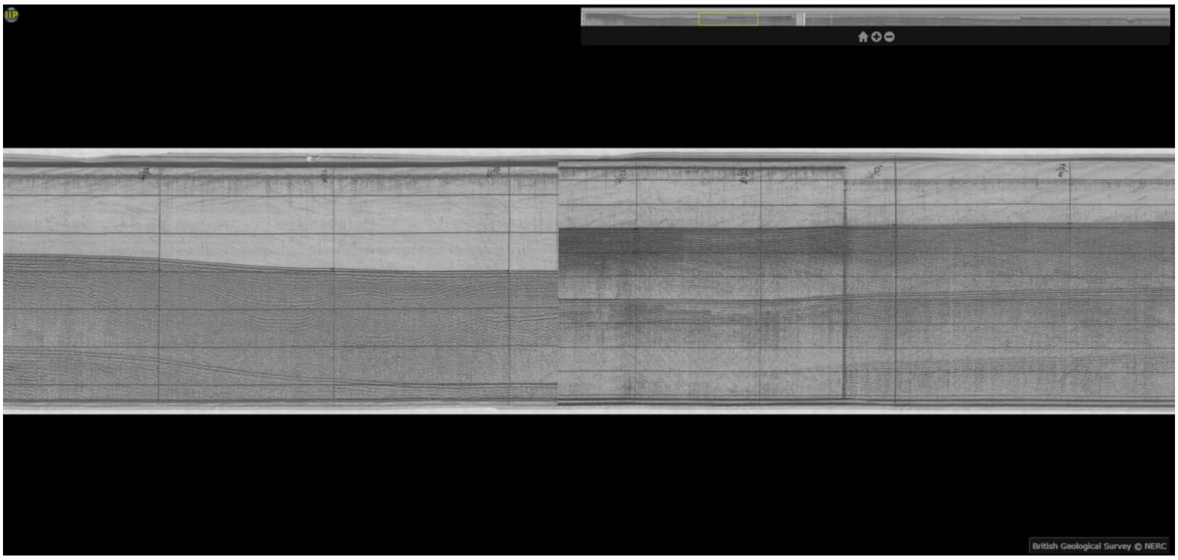


Figure 3.4

3.6 If you are confident that the scanned data will provide useful information, go back to the GIS project, and in the Pop-up, scroll down to the 'SCAN_DOWNL' attribute field. Click on the link there, which will take you to the download page online, agree to the terms and download,

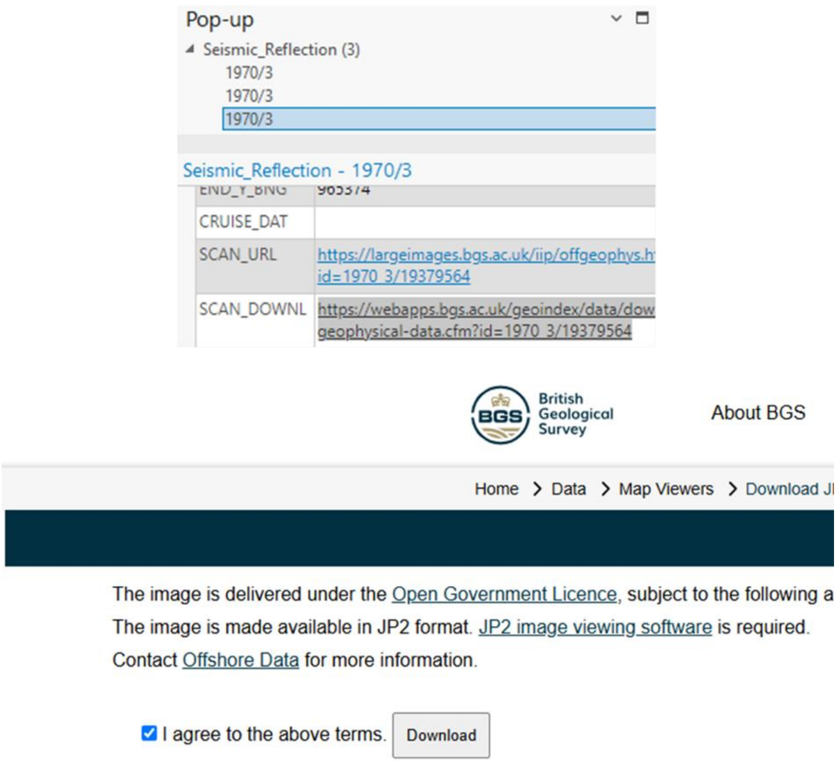


Figure 3.5

3.7 The file will be downloaded to your Downloads folder by default. In your Datasets/Scanned_Seismic folder within your project space, create a new folder called 'Raw_Scanned_Seismic'. Move your downloaded scan file into this new folder.

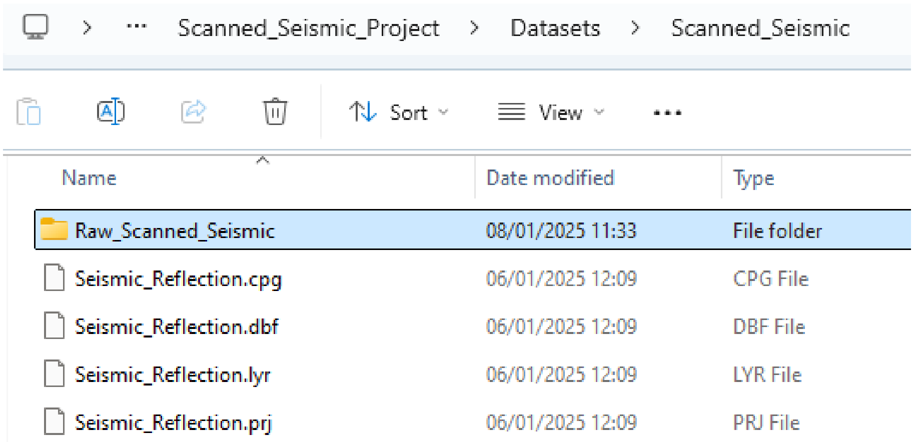


Figure 3.6

3.8 Rename the scan file with the line name and data type (but do not include the / or # in the file name). For example CRUISE_LIN 1970/3#52, GEOPHYS_EQ Sparker becomes 'Sparker_1970_3_52'.

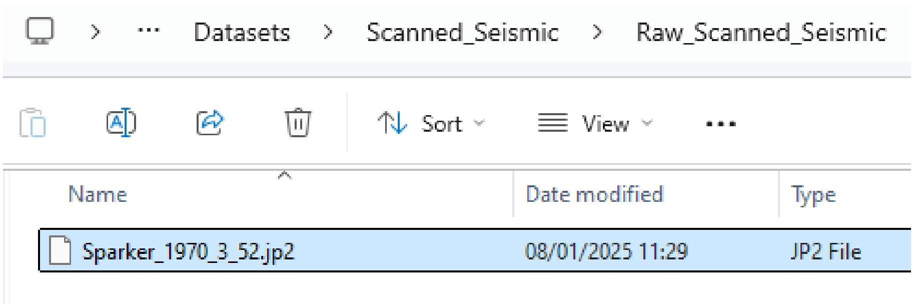


Figure 3.7

3.9 The next step is to prepare the scanned image for import into GIS. To do this you will need to use drawing software, such as CorelDraw or Adobe Illustrator. For the example in this report, we will use CorelDraw.

3.10 Open CorelDraw and create a new document (the default document settings are ok for the purposes of this exercise). Drag and drop the scanned seismic .jpg2 file into blank page (it may take a few moments for the image to load on the page).

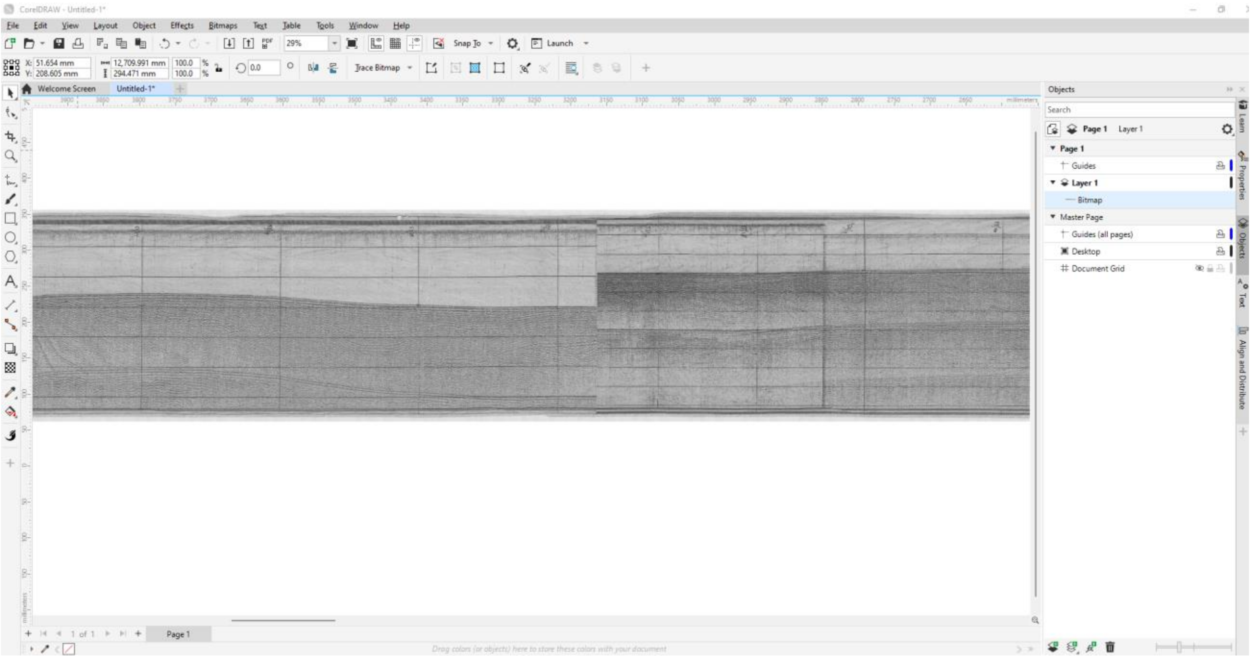


Figure 3.8

3.11 Create another new folder in your Datasets/Scanned_Seismic folder called 'Image_Prep_CorelDraw' save your CorelDraw file to this location with the same name as the name you gave to the scan, but with the suffix '_prep'.

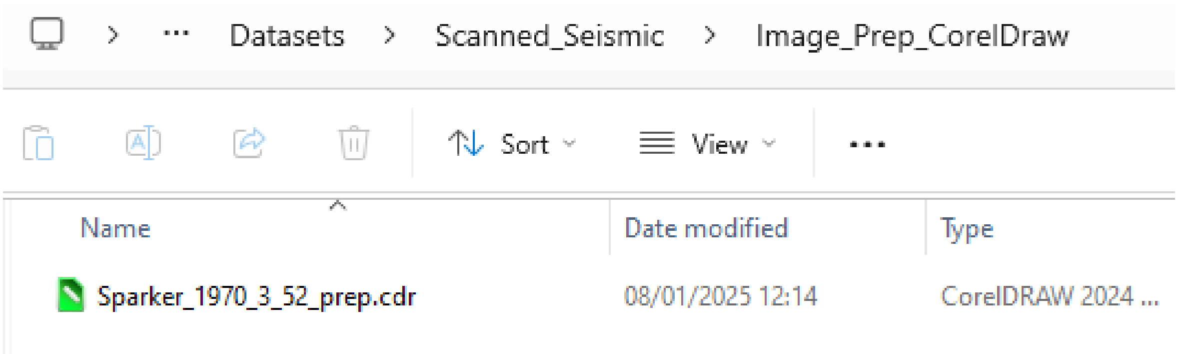


Figure 3.9

3.12 If the data has “steps”, where the grid lines long the length of the image do not line up (as is the case for the example here), you’ll need to duplicate the image and then use the crop tool, probably multiple times, so that you have a series of separate images without these steps.

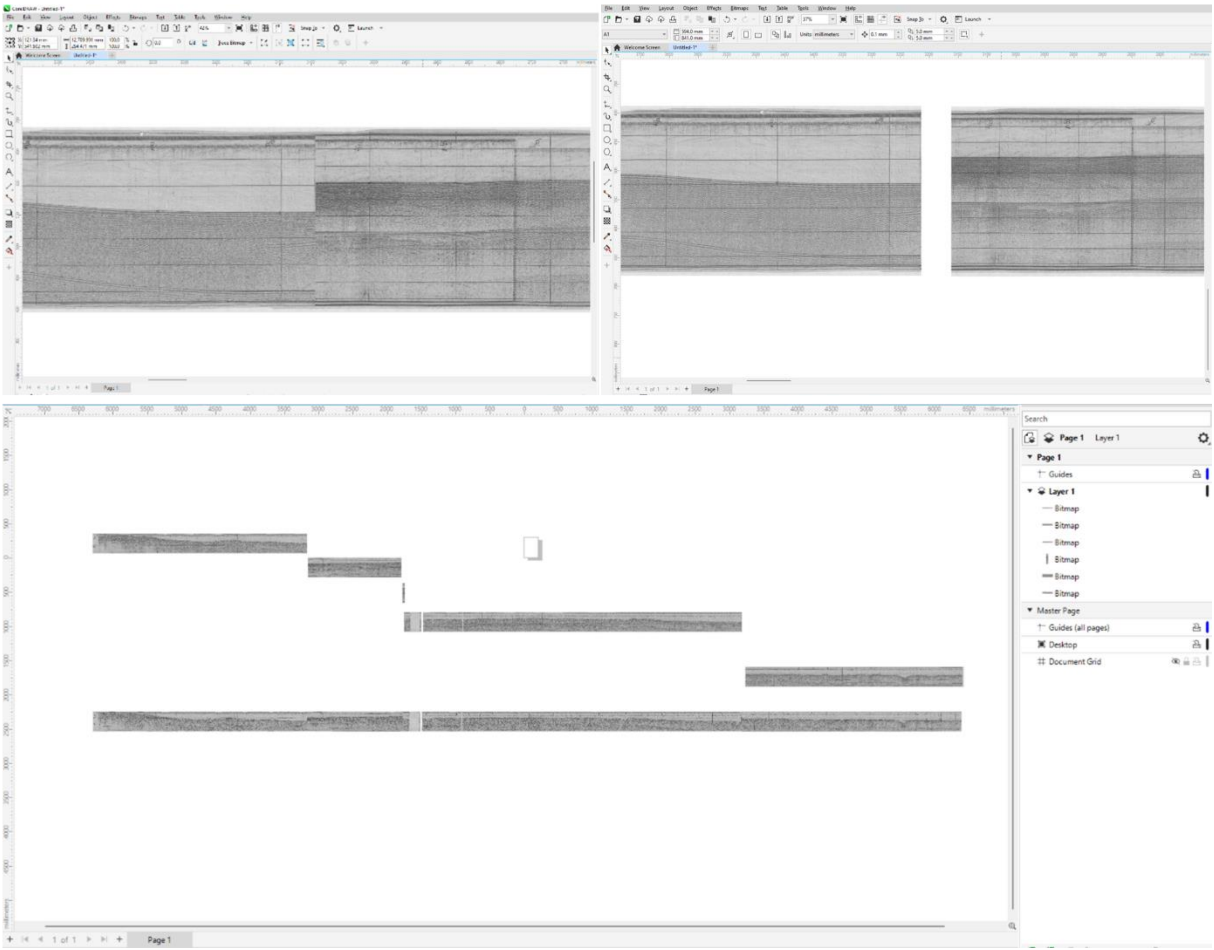


Figure 3.10

3.13 Each segment of the image you now have will need to be exported as separate image. First create another new folder within your Datasets/Scanned_Seismic/Image_Prep_CorelDraw folder space and call it the name of the seismic line you’re working on, with the suffix ‘_noref_jpegs’.

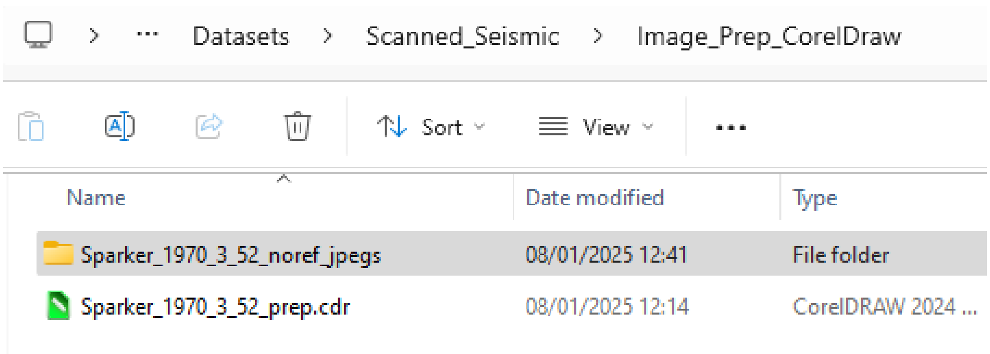


Figure 3.11

3.14 Starting with the image that was cropped from the first part of the seismic line, select the single image in CorelDraw, then go to 'File > Export'. Navigate to the folder you just created, ensure that the 'Selected only' checkbox is ticked, and give the export the name of the seismic line with the suffix '_part1', make sure that the 'Save as type' is set to 'JPG – JPEG Bitmaps..', Save. The default settings in the dialogue that appears should be ok, but you might decide to change the quality from 'High' to 'Highest', click OK.

Repeat this process for all of the other image segments you have for as many parts as you need. If you only have one part (if there were no 'steps') just save the one image.

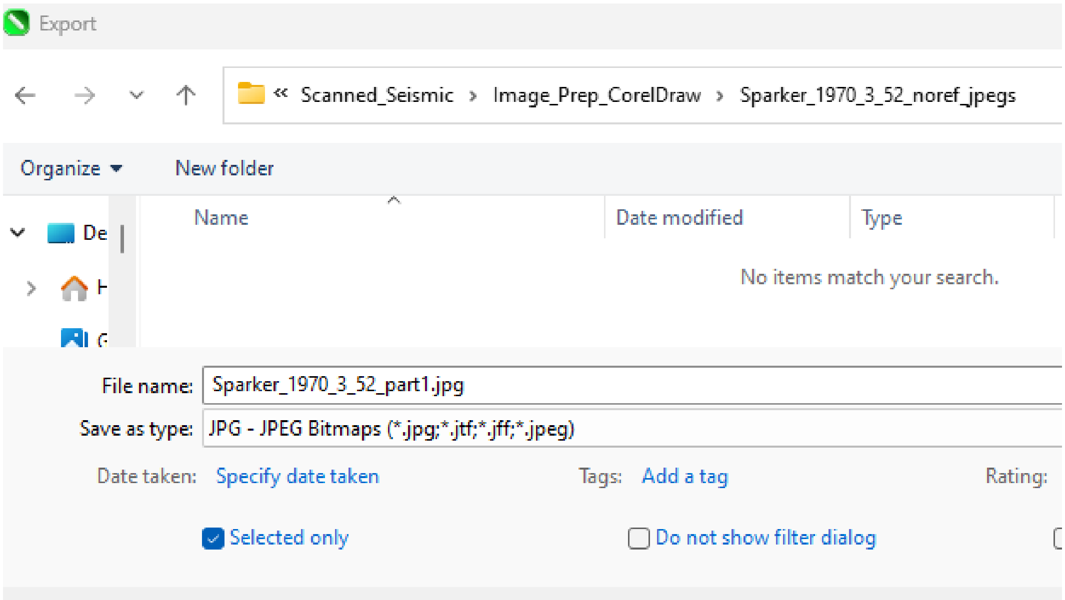


Figure 3.12

The next stage will be to import these images into your GIS project and "georeference" them to a pseudo map space that approximates a distance versus two-way-time plane, from which picks can be made returning X (distance) Y (TWT) coordinates. Those picks can then be ultimately converted to XYZ (X – Easting; Y – Northing; Z – TWT) points to be gridded.

4 ADD SPATIAL REFERENCE TO SCANNED SEISMIC

The next aspect of this workflow will be carried out within your GIS project.

4.1 Within your GIS project, go to the Insert tab and click on 'New Map'. Change the name of this map to the name of the Seismic line you are going to work on – in the example detailed in this report – Sparker_1970_3_52.

4.2 Remove the 'World Topographic Map' and the 'World Hillshade' layers from the map so that you have a blank canvas.

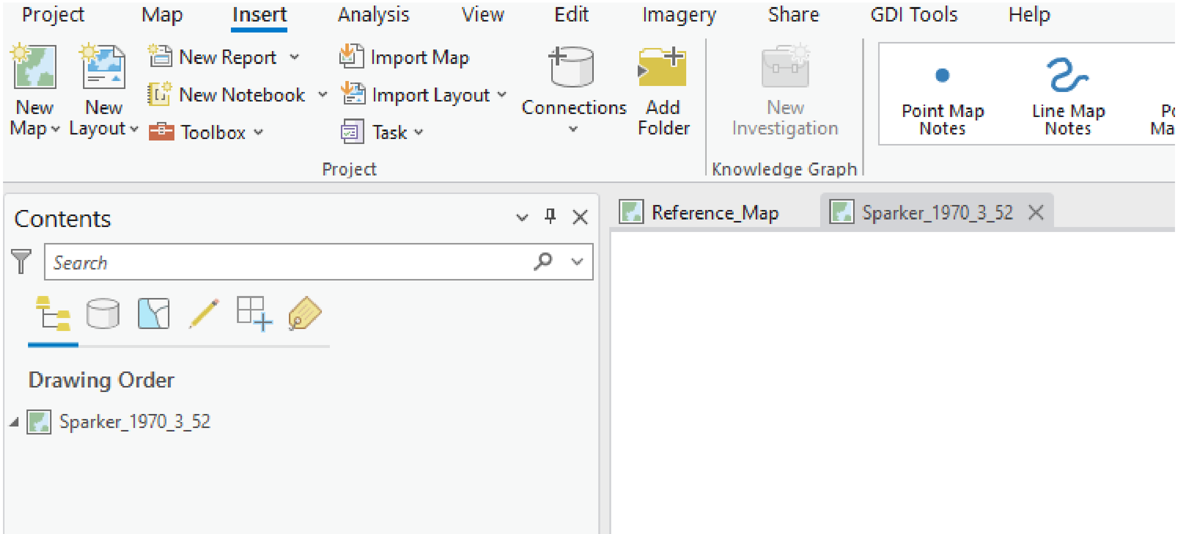


Figure 4.1

4.3 Right-click on the map name in the table of contents, go to properties and select Coordinate System, select a projected coordinate system that uses metres as the map unit e.g., British National Grid.

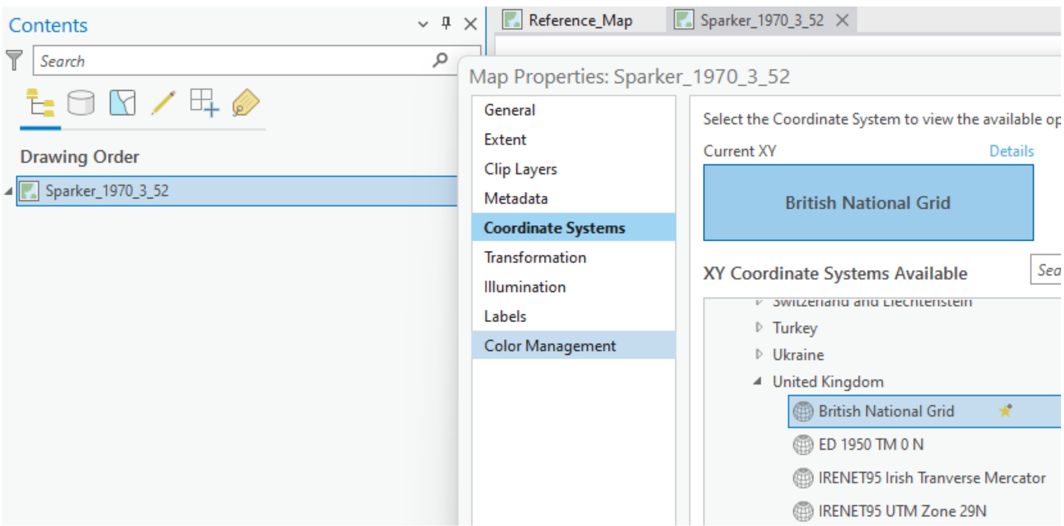


Figure 4.2

4.4 At the bottom of the map window, click the drop-down arrow next to where the cursor location is displayed and change the display units to metres.

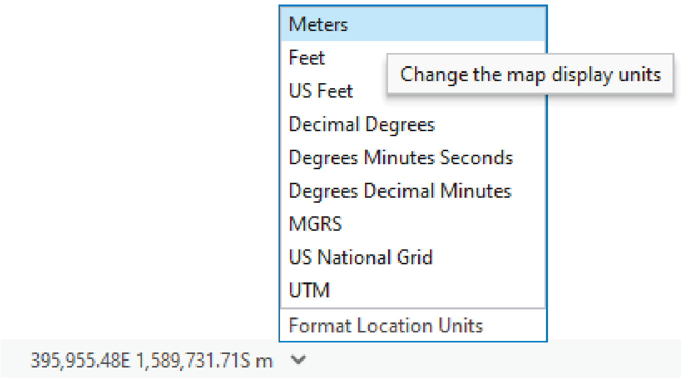


Figure 4.3

4.5 Click on the 'Map' tab in the top ribbon of your project and select 'Go To XY' from the top ribbon in the 'Navigate' tab. Change the units from the default 'dd' to 'Metres' and enter 0 for both X and Y and press enter.

Figure 4.4

This map space is now ready to add a pseudo-spatial reference to the JPEGs from the scanned seismic you created in section 2.3.

4.6 Open the Catalog Pane (if it was closed you will need to go to the View tab and click on Catalog Pane). Within the Catalog Pane, Expand 'Folders' and expand the folders using the small arrows to navigate to where you exported your JPEGs from CorelDraw.

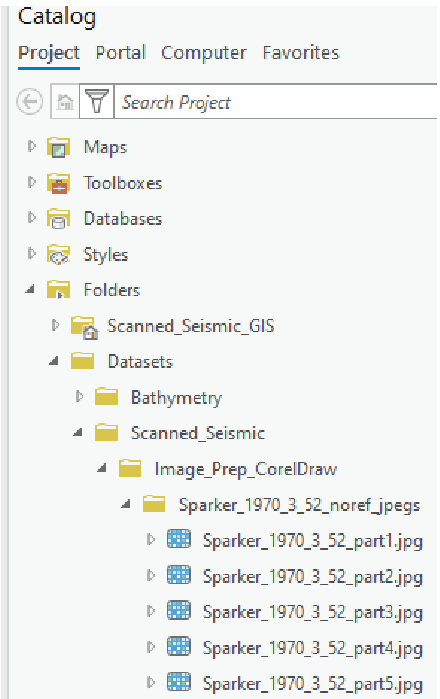


Figure 4.5

4.7 Check which of the image files (jpegs) clearly has a number of horizontal and vertical grid lines – this will be important for the following georeferencing process – and choose one of these images to work on first. Drag and drop your chosen first image into the map space. Click Ok if you are asked to Build Pyramids.

Right-click on the image in the table of contents and zoom to layer.

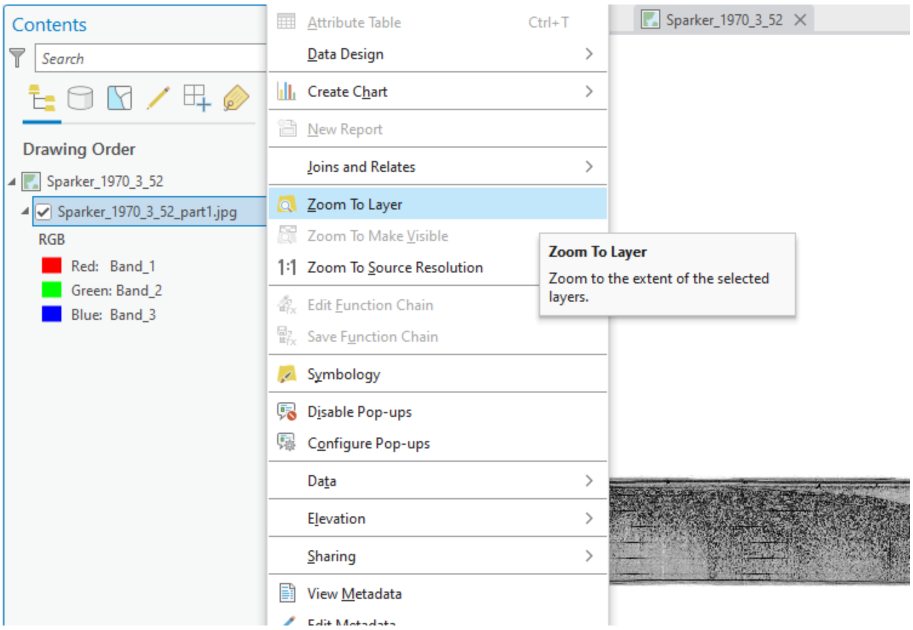


Figure 4.6

4.8 Have a look at the original image for the scan, somewhere, probably on the left-hand side of the image, there may be an information box with some hand-written details. The important information to make a note of here is the 'T. Marks' – which tells you the two-way-time interval at which the horizontal grid lines are drawn. In Figure 4.7 below, the example on the left shows that the interval is 40 ms, whereas the example on the right for data from a different cruise, indicates that the interval for that data is 100 ms.

Be careful and check through the data you are using thoroughly to ensure you use the right interval for your data. This report will use the data with 40 ms intervals as **the example.**

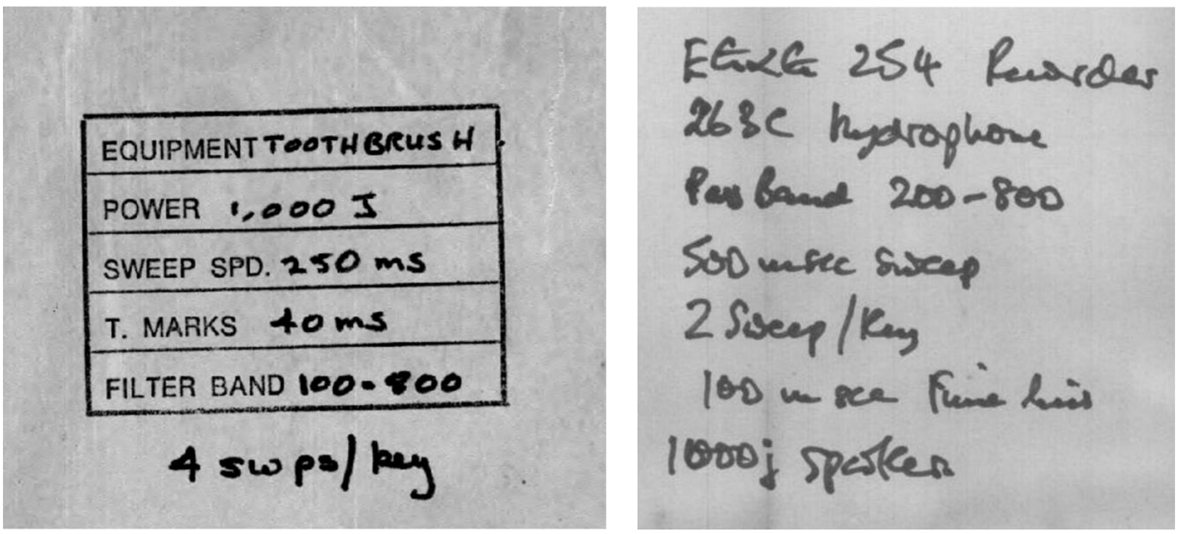


Figure 4.7

4.9 In your GIS project, on the map space for the seismic line, zoom in on the image to where you see the grid lines, you should see labels for the vertical grid lines. These labels refer back to the ‘Shot_Points’ shapefile you have plotted in your Reference_Map, specifically the ‘FIX’ attribute of that shapefile. In the example below (Figure 4.8) the label ‘52/2’ refers to the Shot_Points shapefile feature with attributes: CRUISE_LIN 52 and FIX 2 (cruise line 52, shot point 2).

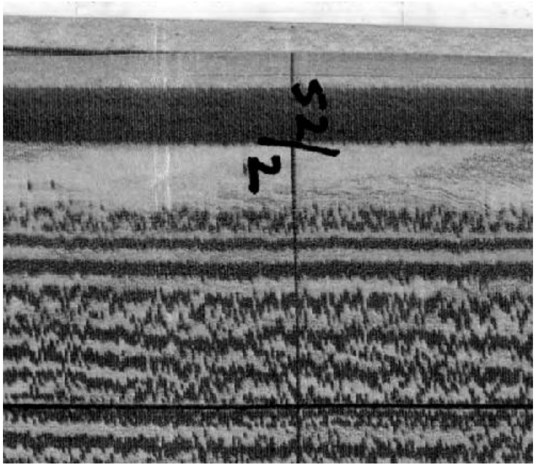


Figure 4.8

4.10 To check this, go to your Reference_Map in your GIS project, right-click on the Shot_Points layer and open the attributes table. In the attributes table, right-click on the ‘CRUISE_LIN’ column, and click on ‘Custom Sort’.

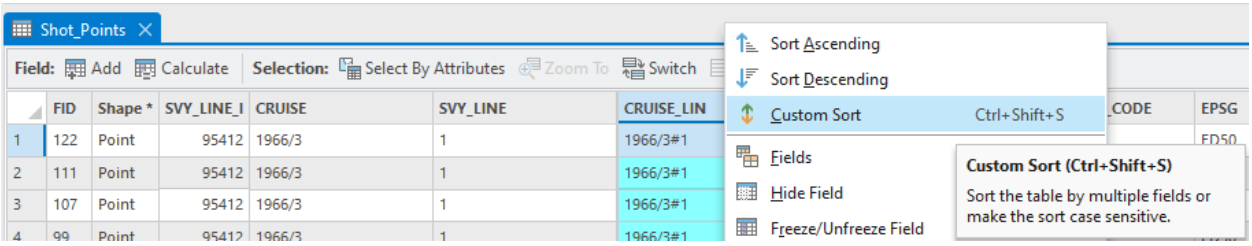


Figure 4.9

4.11 In the dialogue box that opens, choose ‘Ascending’ as the Sort method for ‘CRUISE_LIN’, and then add ‘FIX’ as the second field, and choose ‘Ascending’ as the Sort method for this as well. Click OK.

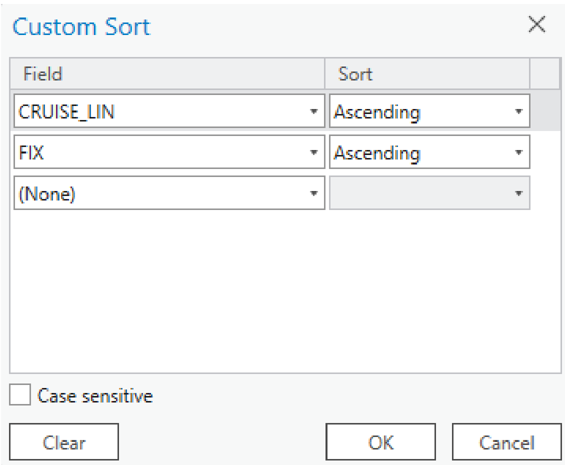


Figure 4.10

4.12 Scroll down in the attributes table to the CRUISE_LIN you are working on – in this example, 1970/3#52. The important things to note here are the coordinates that relate to the shot points at the vertical grid lines on your scan that you are going to use to add a spatial reference. Specifically the X_BNG and Y_BNG coordinates.

	CRUISE_LIN	FIX	SUBFIX	DATETIME	EPSG_...	EP...	X	Y	XY_SOURCE	X_ED50	Y_ED50	X_WGS84	Y_WGS84	X_BNG	Y_BNG
2450	1970/3#51	10	0	03/06/1970	4230	ED50	-3.336	57.7454	Main Chain De...	-3.336	57.7454	-3.337703	57.744705	320467.41903	873561.72111
2451	1970/3#51	11	0	03/06/1970	4230	ED50	-3.3733	57.7404	Main Chain De...	-3.3733	57.7404	-3.375004	57.739705	318235.83526	873049.52257
2452	1970/3#51	12	0	03/06/1970	4230	ED50	-3.4148	57.7351	Main Chain De...	-3.4148	57.7351	-3.416505	57.734404	315752.88332	872510.3744
2453	1970/3#51	13	0	03/06/1970	4230	ED50	-3.4535	57.7305	Main Chain De...	-3.4535	57.7305	-3.455205	57.729803	313437.64013	872047.09236
2454	1970/3#52	1	0	03/06/1970	4230	ED50	-3.5215	57.6982	Main Chain De...	-3.5215	57.6982	-3.523206	57.697501	309307.5943	868540.43212
2455	1970/3#52	2	0	03/06/1970	4230	ED50	-3.4936	57.7131	Main Chain De...	-3.4936	57.7131	-3.495306	57.712402	311007.03441	870162.08683
2456	1970/3#52	3	0	03/06/1970	4230	ED50	-3.4633	57.7275	Main Chain De...	-3.4633	57.7275	-3.465006	57.726803	312846.84779	871725.69761
2457	1970/3#52	4	0	03/06/1970	4230	ED50	-3.4327	57.7423	Main Chain De...	-3.4327	57.7423	-3.434405	57.741604	314704.04421	873334.28811
2458	1970/3#52	5	0	03/06/1970	4230	ED50	-3.4014	57.757	Main Chain De...	-3.4014	57.757	-3.403105	57.756305	316601.1917	874931.72974
2459	1970/3#52	6	0	03/06/1970	4230	ED50	-3.3711	57.7718	Main Chain De...	-3.3711	57.7718	-3.372805	57.771106	318437.5862	876542.3911
2460	1970/3#52	7	0	03/06/1970	4230	ED50	-3.3392	57.7856	Main Chain De...	-3.3392	57.7856	-3.340905	57.784907	320365.4516	878040.67396
2461	1970/3#52	8	0	03/06/1970	4230	ED50	-3.3074	57.7995	Main Chain De...	-3.3074	57.7995	-3.309105	57.798808	322286.15589	879551.11826
2462	1970/3#52	9	0	03/06/1970	4230	ED50	-3.2763	57.8126	Main Chain De...	-3.2763	57.8126	-3.278005	57.811909	324162.15153	880974.19473

Figure 4.11

Now that you know where to find the relevant coordinates, you can begin adding the initial spatial reference for the image. **Note that this process uses a 'fudge' whereby the X and Y positions you add to the map are a proxy for XZ coordinates of the vertical plane of the seismic section.** Later outside of GIS you can convert the coordinates into XYZ. However, also note the caveat that this process assumes that the seismic line you're working with is a straight line (small deviations from a straight line are acceptable for this purpose, but if the section is dog-legged it should be slit up into approx. straight-line segments).

4.13 Make sure the jpeg you want to add the spatial reference to is selected in the table of contents and then go to the 'Imagery' tab in ArcGIS Pro' and click on 'Georeference'. Click on 'Add Control Points'. Zoom in on the intersection of the grid lines at the first shot point and click once.

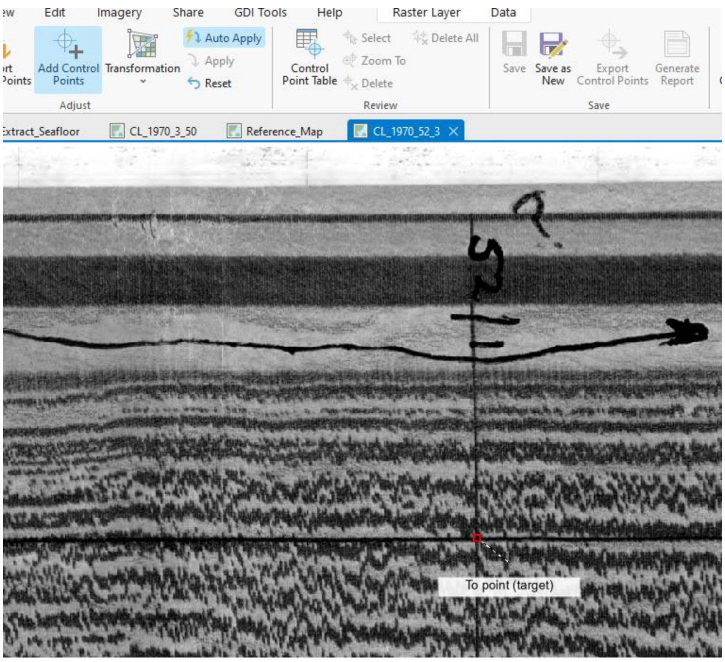


Figure 4.12

4.14 Right-click and a 'Target Coordinates' dialogue will open. For the X coordinate, enter 0 (assuming your control point is at the first shot point). The coordinates will be converted to the true coordinates later.

For the Y coordinate, there is some more 'fudging'. For the example in the image for step 4.13, the control point has been added at the first 'T.Mark' after the record start, so at 40 ms for this scan. However, given the length of the image and the vertical exaggeration, enter a value that will preserve a useful aspect ratio for the image. **So, a suggestion would be 10x the ms value.** Additionally, we want to the values to represent elevation in time, so they should be negative (this will be important later and to ensure the image doesn't flip upside down).

Enter your value (e.g., -400 for the example) for the Y coordinate. Press OK.

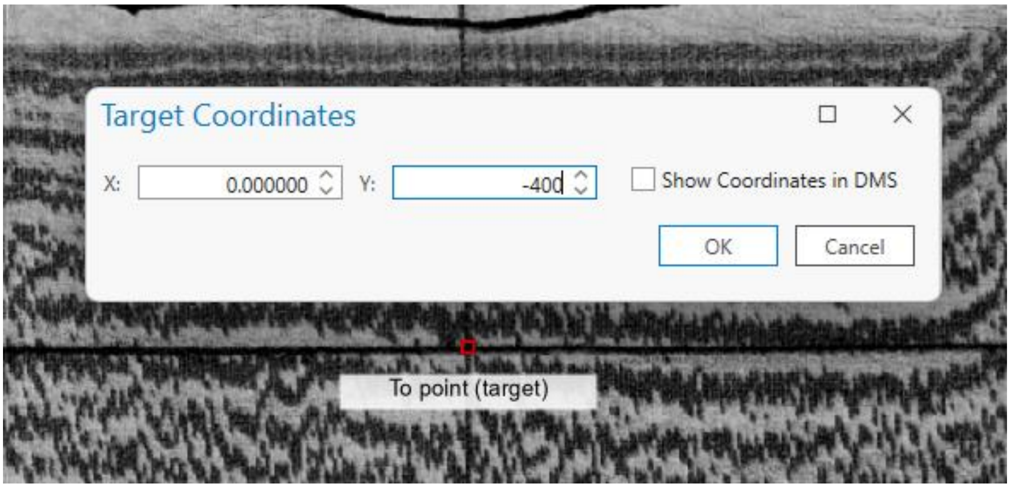


Figure 4.13

4.15 Scroll to the other end of the image and find another point where the grid lines cross. Look at what the shot point number is – double check the shot point numbers on adjacent vertical grid lines, because the handwriting may be difficult to decipher e.g., in the example below (Figure 4.14) the shot point number is 16.

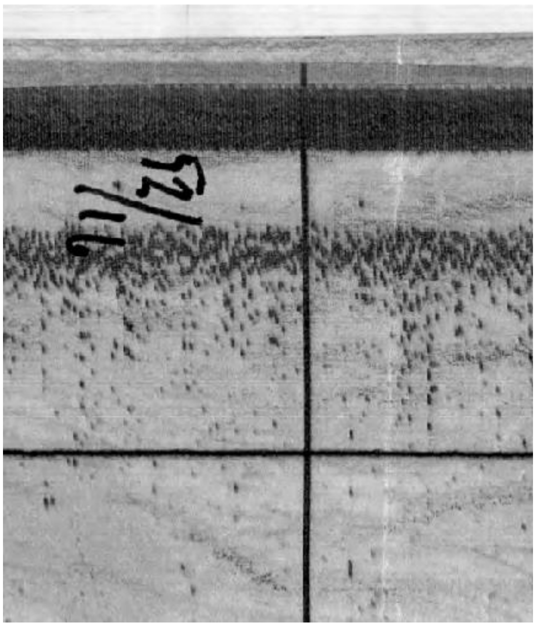


Figure 4.14

4.16 Getting a useful X value for this second shot point location and subsequent locations is more involved. Go back to the attributes table for Shot_Points (as in step 4.12) and make a note of the X_BNG and Y_BNG values for this shot point (as well as the first shot point or the first shot point that you added a control point for).

For the example here (Figure 4.15), shot point 1 has: X_BNG 309307.5943 Y_BNG 868540.43212; and shot point 16 has: X_BNG 337677.60968 Y_BNG 890563.66588.

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

	CRUISE_LIN	FIX	SUBFIX	DATETIME	EPSG_...	EP...	X	Y	XY_SOURCE	X_ED50	Y_ED50	X_WGS84	Y_WGS84	X_BNG	Y_BNG
2454	1970/3#52	1	0	03/06/1970	4230	ED50	-3.5215	57.6982	Main Chain De...	-3.5215	57.6982	-3.523206	57.697501	309307.5943	868540.43212
2455	1970/3#52	2	0	03/06/1970	4230	ED50	-3.4936	57.7131	Main Chain De...	-3.4936	57.7131	-3.495306	57.712402	311007.03441	870162.08683
2456	1970/3#52	3	0	03/06/1970	4230	ED50	-3.4633	57.7275	Main Chain De...	-3.4633	57.7275	-3.465006	57.726803	312846.84779	871725.69761
2457	1970/3#52	4	0	03/06/1970	4230	ED50	-3.4327	57.7423	Main Chain De...	-3.4327	57.7423	-3.434405	57.741604	314704.04421	873334.28811
2458	1970/3#52	5	0	03/06/1970	4230	ED50	-3.4014	57.757	Main Chain De...	-3.4014	57.757	-3.403105	57.756305	316601.1917	874931.72974
2459	1970/3#52	6	0	03/06/1970	4230	ED50	-3.3711	57.7718	Main Chain De...	-3.3711	57.7718	-3.372805	57.771106	318437.5862	876542.3911
2460	1970/3#52	7	0	03/06/1970	4230	ED50	-3.3392	57.7856	Main Chain De...	-3.3392	57.7856	-3.340905	57.784907	320365.4516	878040.67396
2461	1970/3#52	8	0	03/06/1970	4230	ED50	-3.3074	57.7995	Main Chain De...	-3.3074	57.7995	-3.309105	57.798808	322286.15589	879551.11826
2462	1970/3#52	9	0	03/06/1970	4230	ED50	-3.2763	57.8126	Main Chain De...	-3.2763	57.8126	-3.278005	57.811909	324162.15153	880974.19473
2463	1970/3#52	10	0	03/06/1970	4230	ED50	-3.2457	57.8252	Main Chain De...	-3.2457	57.8252	-3.247405	57.824509	326006.09862	882343.02207
2464	1970/3#52	11	0	03/06/1970	4230	ED50	-3.2134	57.8377	Main Chain De...	-3.2134	57.8377	-3.215104	57.83701	327949.52752	883699.74376
2465	1970/3#52	12	0	03/06/1970	4230	ED50	-3.1806	57.8504	Main Chain De...	-3.1806	57.8504	-3.182304	57.849711	329921.70723	885079.1454
2466	1970/3#52	13	0	03/06/1970	4230	ED50	-3.1478	57.8626	Main Chain De...	-3.1478	57.8626	-3.149504	57.861912	331891.58488	886403.84393
2467	1970/3#52	14	0	03/06/1970	4230	ED50	-3.1145	57.8745	Main Chain De...	-3.1145	57.8745	-3.116204	57.873813	333889.26529	887695.61456
2468	1970/3#52	15	0	03/06/1970	4230	ED50	-3.082	57.8869	Main Chain De...	-3.082	57.8869	-3.083703	57.886214	335839.10771	889044.79668
2469	1970/3#52	16	0	03/06/1970	4230	ED50	-3.0514	57.9008	Main Chain De...	-3.0514	57.9008	-3.053103	57.900115	337677.60968	890563.66588

Figure 4.15

4.17 To ensure you avoid any errors that may be the result of poor positioning when the shot point locations were originally recorded during data acquisition (during the cruise), double check that the points match (at least to within a few metres). To do this, find the shot point(s) you have selected on the map, right click on one using the select tool and go to copy coordinates – you can then paste these in excel/word, and check the ones from the attributes table against them. If significantly different – use the coordinates copied this way, as you know they will match the line feature's position (important for matching to the bathymetry later on).

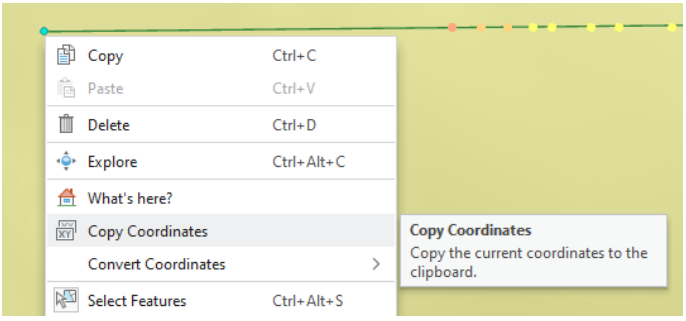


Figure 4.16

4.18 The distance along the line between the these points needs to be calculated by $\sqrt{(\Delta x)^2 + (\Delta y)^2}$ so i.e., $((337677.60968 - 309307.5943)^2 + (890563.66588 - 868540.43212)^2)^{1/2}$ = **35914.90774**

Note that you may need to think carefully about the orientation of the line, the example provided here is simple, because both X and Y increase as the shot point value increases, but this may not always be the case e.g., a different survey line may have been acquired from north-east to south-west. In cases where X and/or Y decrease as shot points increase, you just need to find the absolute value of Δx and Δy but keep a note of the orientation for later on when you come to convert your pseudo spatial information to the true XY coordinates.

4.19 Repeat steps 4.13 and 4.14 for the second grid line intersection (shot point 16 in the example Figure 4.14) and use the value calculated in step 4.17 as the X coordinate.

If you use another shot point other than the first shot point where the X value was ultimately 0 to make your calculation, remember to add the result to the X value of the shot point you are using instead, so that the X values are always increasing (see step 4.22 for more explanation).

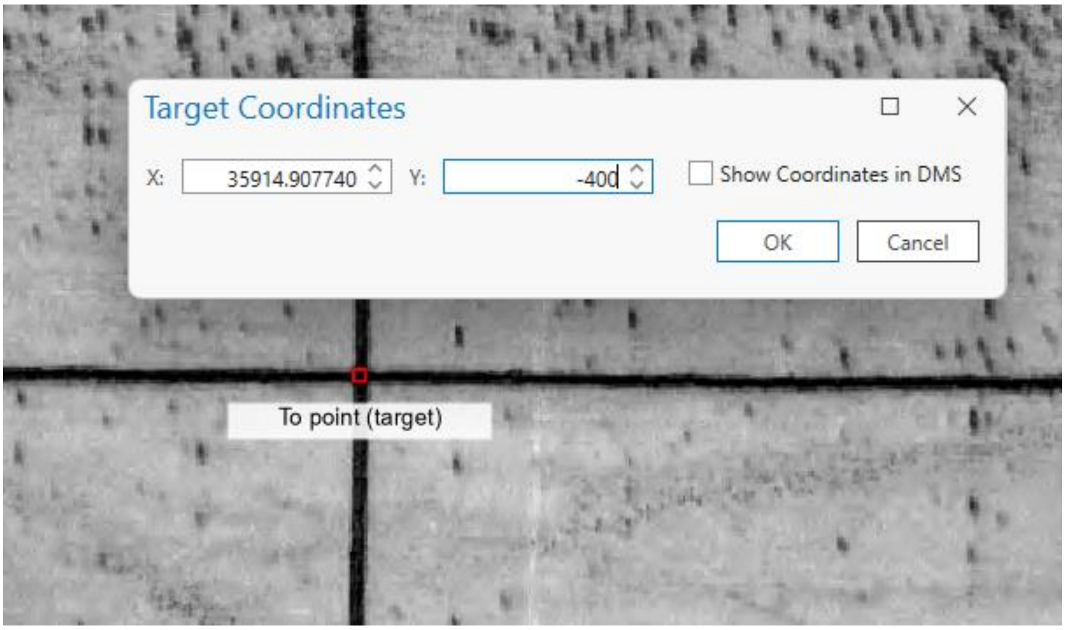


Figure 4.17

4.20 Now you need another two control points at depth. Use the same vertical grid lines, but the deepest horizontal grid line. Count the number of horizontal grid lines to calculate the elevation in time. In the example here, the deepest horizontal grid line (T. Mark) is 6 from the record start, so 6 x 40 ms – 240 ms, so -2400 should be entered as the Y coordinate.

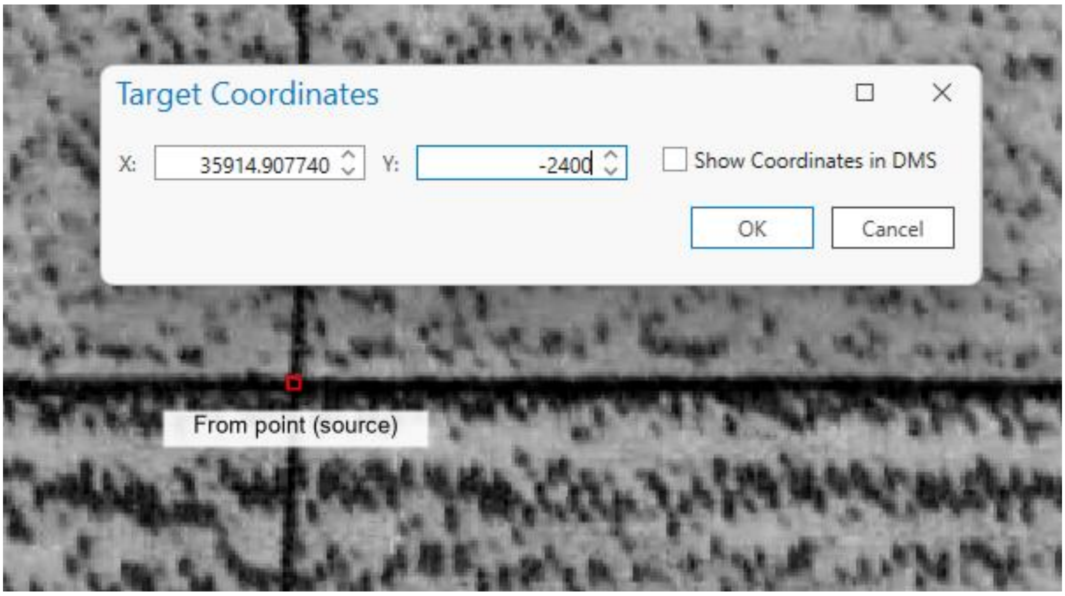


Figure 4.18

4.21 Save the Georeference using the save button in the top ribbon. Then Close Georeference.

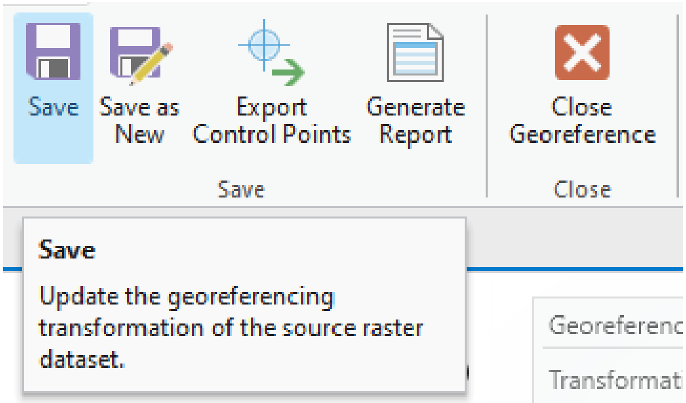
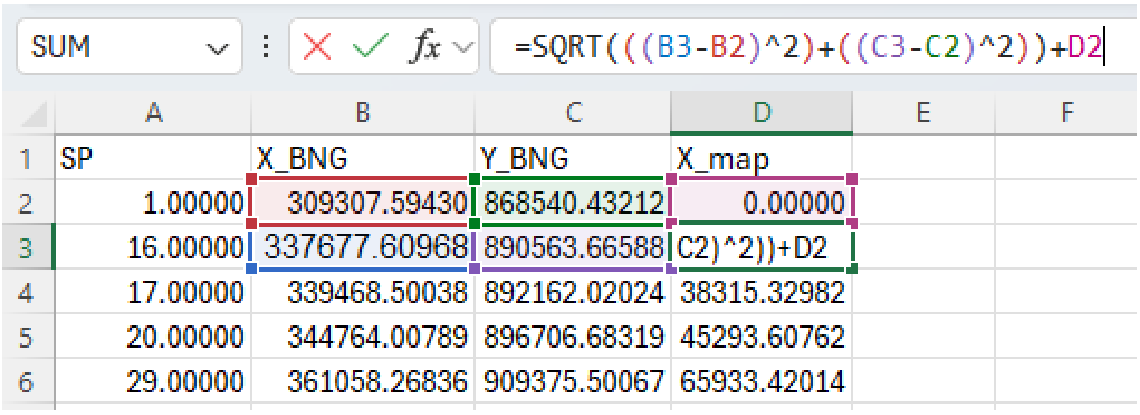


Figure 4.19

4.22 If you split the line into segments (because there are steps/scan offsets/scaling issues, but the line is still straight) then repeat for the other segments on this same map.
Close the georeference toolbar, click on the next image you want to georeference then open the georeferenced toobar again. Note you will have to work out the offset for the shot points as you did for step 4.16 and 4.17. You may want to use an excel sheet as an aid.


SUM =SQRT(((B3-B2)^2)+((C3-C2)^2))+D2

	A	B	C	D	E	F
1	SP	X_BNG	Y_BNG	X_map		
2	1.00000	309307.59430	868540.43212	0.00000		
3	16.00000	337677.60968	890563.66588	C2)^2))+D2		
4	17.00000	339468.50038	892162.02024	38315.32982		
5	20.00000	344764.00789	896706.68319	45293.60762		
6	29.00000	361058.26836	909375.50067	65933.42014		

Figure 4.20

4.23 You may notice the vertical grid lines are a bit hit and miss on the scans, so you'll have to use your initiative, but try to use vertical grid lines that are as far apart as possible for your georeferencing control points.

4.24 If you are using the same line as in the worked example detailed in this report, and assuming you downloaded the same coverage of the Seismic_Reflection and Shot_Points shapefiles to get coordinate values for the full length of the scan, you should end up with something that looks like the image below.

Figure 4.21

4.25 Check that the horizontal grid lines line up as you're expecting. There may be gaps between your different images, but this is expected.

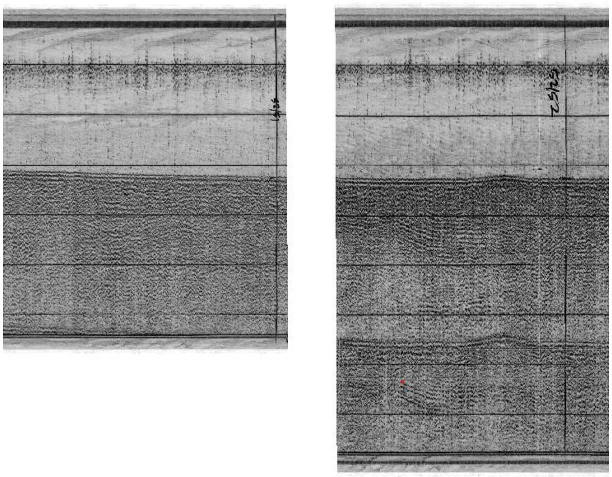


Figure 4.22

The next step is to quality check this against the seabed and adjust the vertical georeference values based on the mistie – the bathymetry data is likely referenced to a lowest astronomical tide (LAT) datum, whereas the seismic data datum maybe somewhat arbitrary.

4.26 The original Seismic_Reflection shapefile coordinate system is decimal degrees, which is problematic for the next step. To avoid issues, we need to create a new shapefile, by creating a new line feature.

In the Catalog pane, find your Datasets/Scanned_Seismic folder, right-click on it, then go to 'New > Folder'.

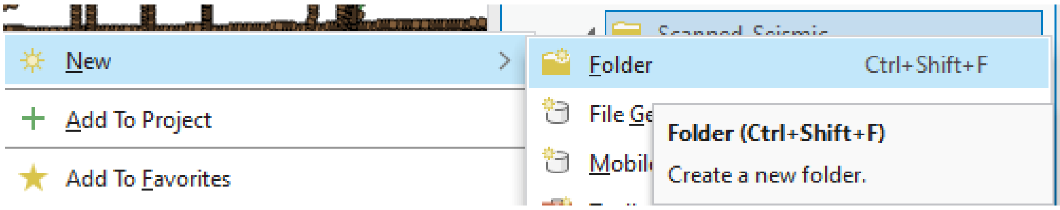


Figure 4.23

Rename the folder 'Scans_w_spatial_info'

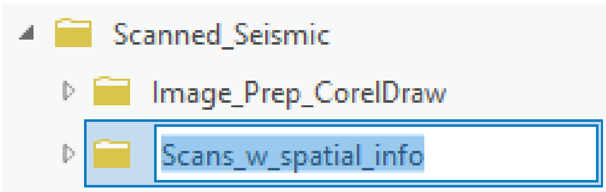


Figure 4.24

Right-click on your newly created folder and go to New > Shapefile.

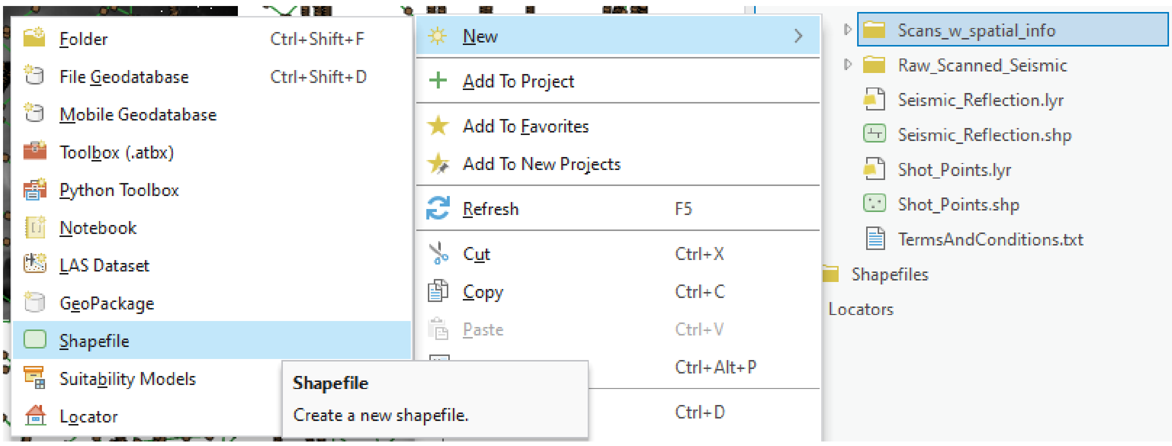


Figure 4.25

4.27 This will open the 'Create Feature Class' Dialogue. In the 'Feature Class Name' field, give an appropriate name, e.g., 'Seismic_w_ref'. Make sure the 'Geometry Type' is set to 'Polyline'. Change the 'Coordinate System' to 'British National Grid' (use the globe icon to find the coordinate system). Leave the rest of the settings as the defaults. Click Run.

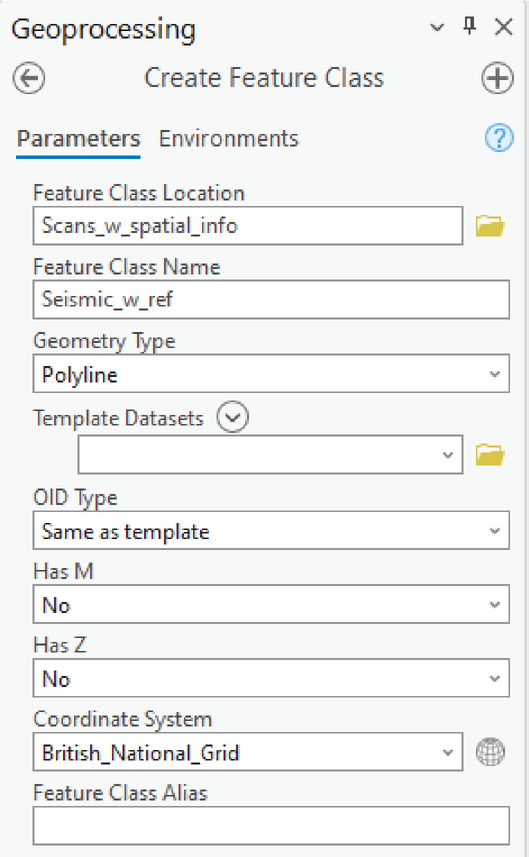


Figure 4.26

4.28 Now you will want to copy the line feature that relates to the scan you've been working on from the original Seismic_Reflection shapefile into this new shapefile.
In your Reference_Map use the select tool to select the individual line feature for the seismic line from the Seismic_Reflection layer, which will highlight it light blue, make sure you only have the one line feature selected (you may want to turn off the 'Shot_Points' layer to avoid accidentally selecting features from this layer). Whilst the feature is selected, go to the 'Edits' tab from the top ribbon and click on 'Copy'.

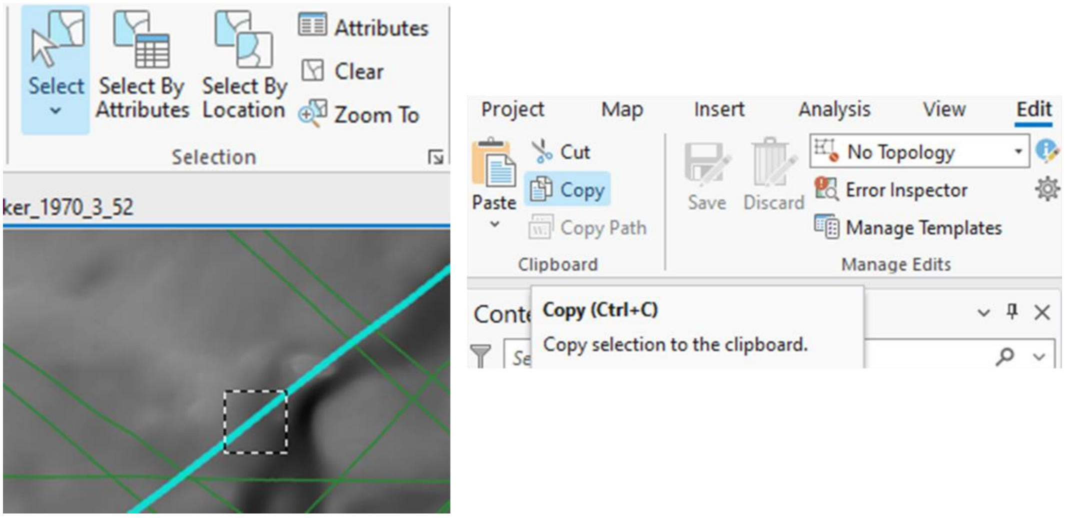


Figure 4.27

4.29 Make sure that your new shapefile layer is turned on then use the drop-down arrow under 'Paste' to select 'Paste Special', a small dialogue box will open, select Layer, and make sure your new Shapefile layer (Seismic_w_ref) is selected from the drop down menu. Press OK.

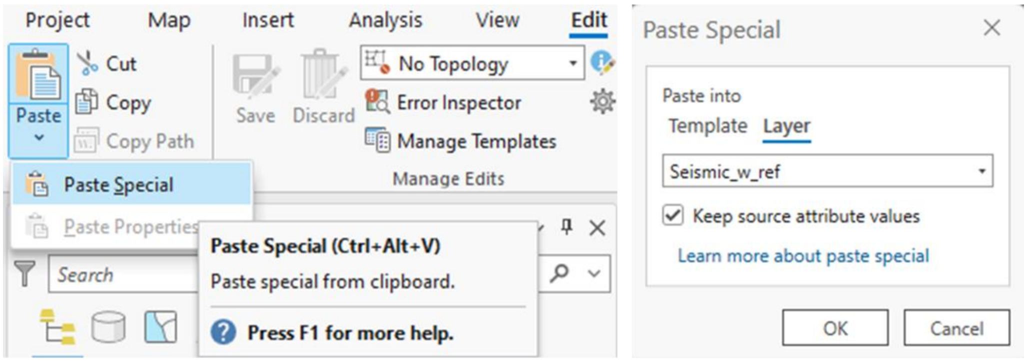


Figure 4.28

4.30 Click on the 'Finish' icon – the square with a tick in it that appears.

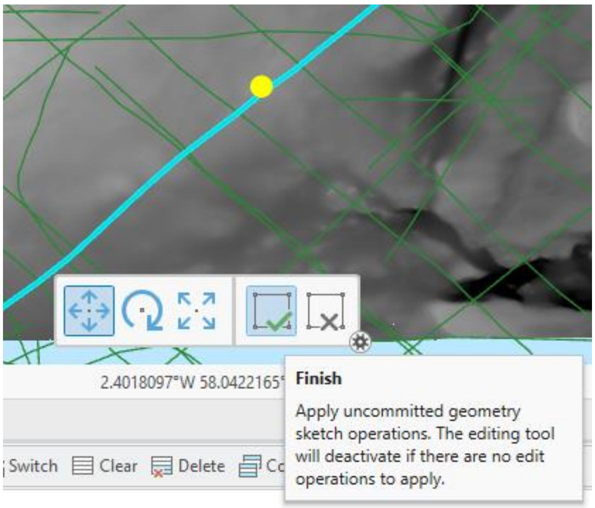


Figure 4.29

4.31 Turn off your original 'Seismic_Reflection' shapefile layer, then use the 'Clear' button in the Selection tools, to deselect your line. You should see that your new shapefile layer has the one line you copied. Save the edits using the save button under the edits tab.

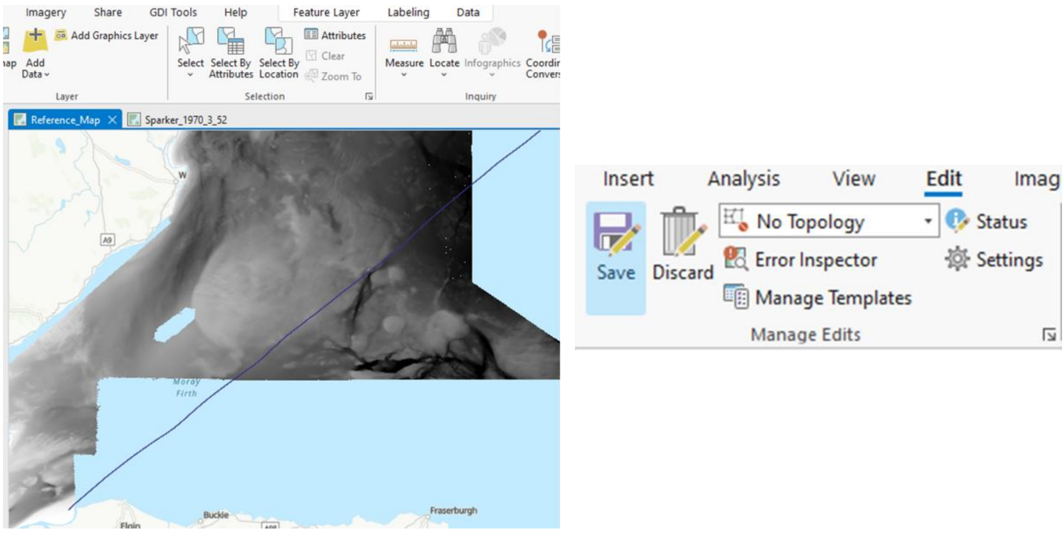


Figure 4.30

4.32 The attributes for the line you copied, probably did not copy over (even if you had the ‘Keep source attribute values’ checkbox ticked).

Right-click on the Seismic_w_ref shapefile in the table of contents and open the attributes table. Next to ‘Field:’ click on ‘Add’. A new tab will open to allow you to edit field names.

For the new field (which will be automatically selected) enter ‘CRUISE_LIN’ for both the ‘Field Name’ and the ‘Alias’. Change the ‘Data Type’ to ‘Text’ using the drop-down.

You can move through the cells using the tab button on your keyboard. Save using the button at the top of ArcPro. Close the ‘Fields’ tab.

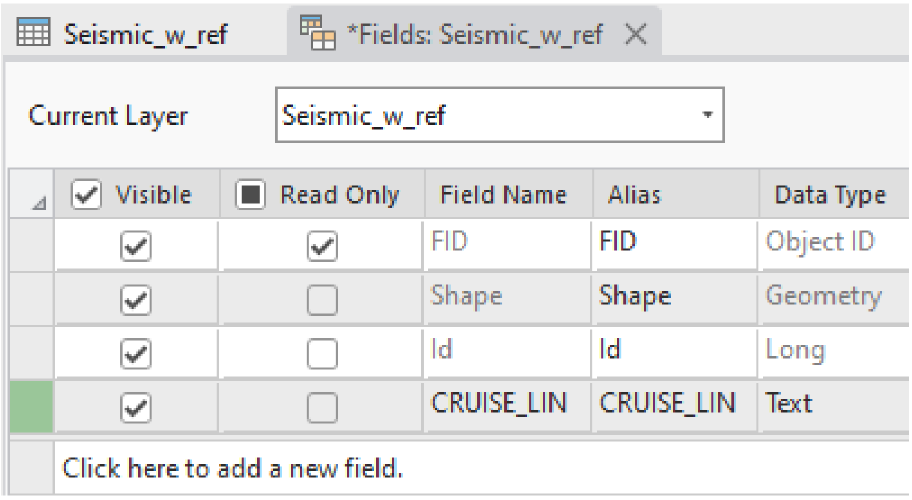


Figure 4.31

4.33 In the attributes table, select one of the rows and then double click in the input box under the ‘CRUISE_LIN’ field. Enter the name of the seismic line, you can either keep this the same as the original, or your updated version e.g., 1970/3#52 or 1970_3_52.

You may have three separate features (for the different data types: Sparker/echo sounder etc), but this line feature is just to have a line in the same location with more workable coordinates, so you can delete duplicates, so you only have one feature for the line. Save the edits again.

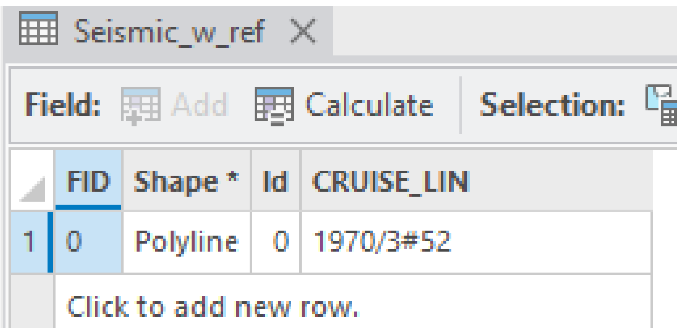


Figure 4.32

4.34 The purpose of creating this new line feature is to extract the seabed two-way-time values where you have data along the length of the line.

Use the select tool to select the line feature, then go to ‘Tool’ from the ‘Analysis’ tab, and search for ‘Stack Profile’.

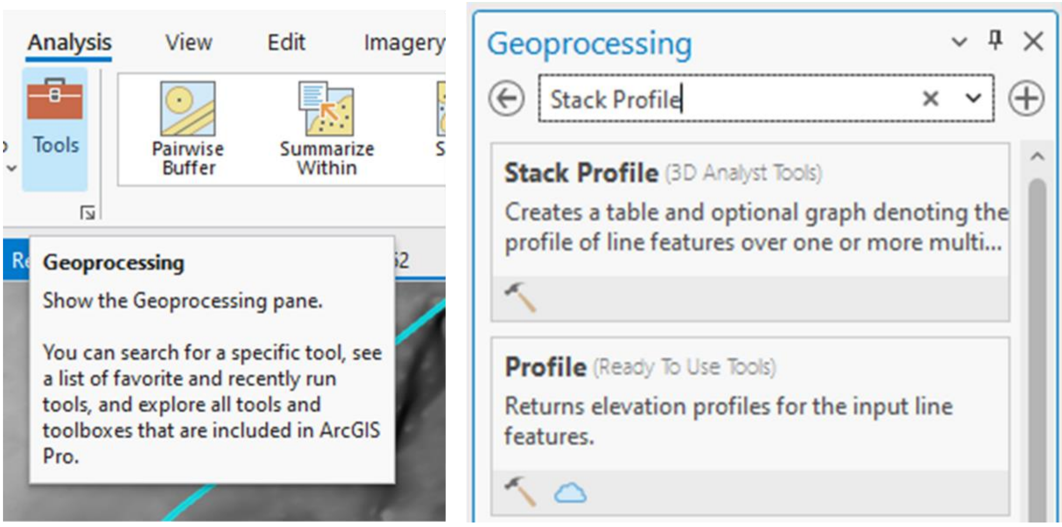


Figure 4.33

4.35 In the Stack Profile dialogue, select your newly created shapefile as the ‘Input Line Features’ and ensure that the ‘Use the selected records’ switch is turned on – you should see that it says 1 record is selected.

Select your two-way-time bathymetry as the Profile Target (note you can select multiple raster targets, should you need to extract other data using this tool).

Use the folder icon next to the ‘Output Table’ to navigate to your Datasets/Scanned_Seismic folder, then create a new folder called ‘Bathy_Along_Profile’, go into this new folder and then save the table as the CRUISE_LIN name, but with the prefix ‘Bathy_’ e.g., ‘Bathy_1970_3_52’. Click ‘Run’ on the Stack Profile dialogue.

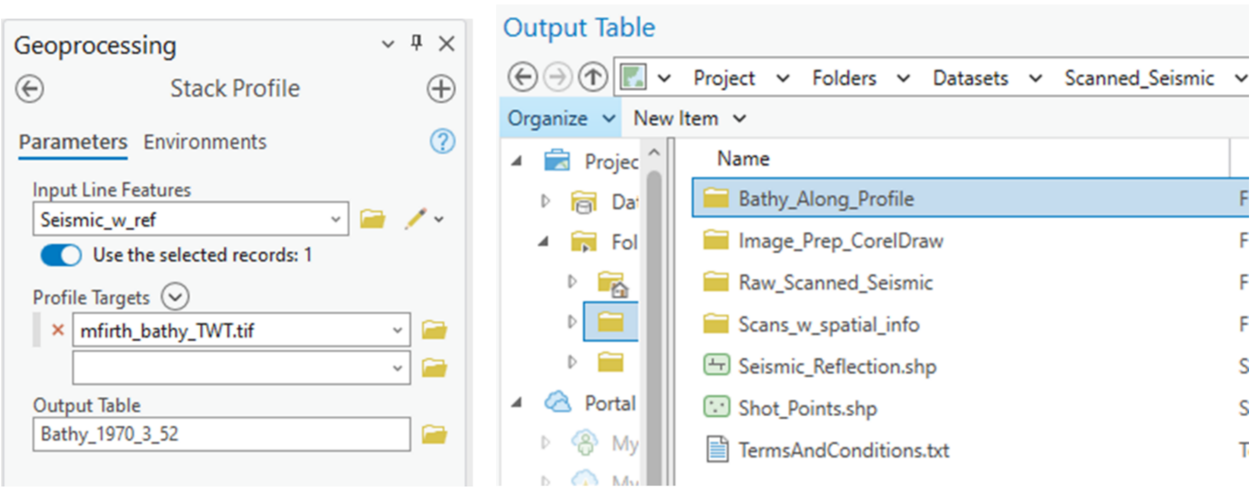
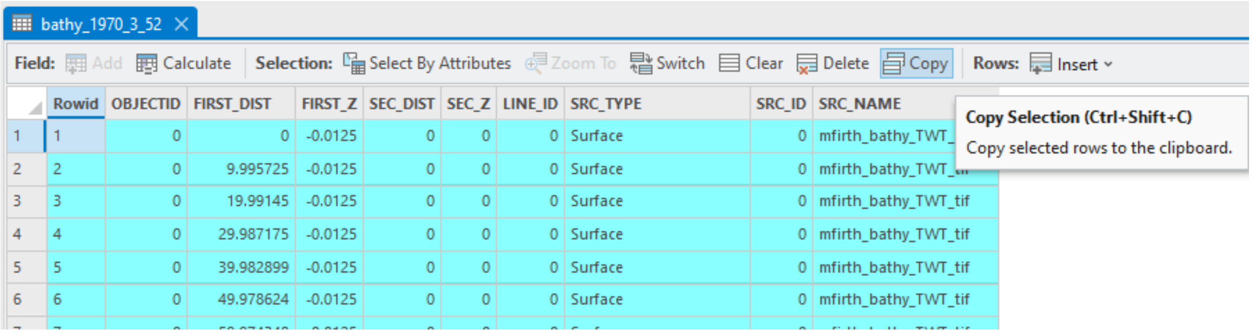


Figure 4.34

4.36 The table should have appeared in the table of contents, right-click on it and select ‘Open’. Click on the grey space in the table window, then use Ctrl + A on your keyboard to select all and then click on ‘Copy’.



	Rowid	OBJECTID	FIRST_DIST	FIRST_Z	SEC_DIST	SEC_Z	LINE_ID	SRC_TYPE	SRC_ID	SRC_NAME
1	1	0	0	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_
2	2	0	9.995725	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_
3	3	0	19.99145	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif
4	4	0	29.987175	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif
5	5	0	39.982899	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif
6	6	0	49.978624	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif

Figure 4.35

4.37 Open Microsoft Excel and create a new blank document. Either use Ctrl + V or right click on the first cell and paste to paste the table from ArcGIS.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Rowid	OBJECTID	FIRST_DIS	FIRST_Z	SEC_DIST	SEC_Z	LINE_ID	SRC_TYPE	SRC_ID	SRC_NAME		
2	1	0	0	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
3	2	0	9.995725	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
4	3	0	19.99145	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
5	4	0	29.98718	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
6	5	0	39.9829	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
7	6	0	49.97862	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
8	7	0	59.97435	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
9	8	0	69.97007	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		
10	9	0	79.9658	-0.0125	0	0	0	Surface	0	mfirth_bathy_TWT_tif		

Figure 4.36

4.38 Delete all the columns except for ‘FIRST_DIST’ and ‘FIRST_Z’.

4.39 In a third column, which you could call ‘Ref_Elev’, calculate FIRST_Z * 10000 (x1000 to convert seconds to milliseconds, and an additional factor of 10 for the ‘fudge’ factor used in step 4.14). Copy the cells from this column, and paste back in the same place as values only by right-clicking and selecting ‘Values’ under the paste options.

	A	B	C
1	FIRST_DIS	FIRST_Z	Ref_Elev
2	0	-0.0125	-125
3	9.995725	-0.0125	-125
4	19.99145	-0.0125	-125
5	29.98718	-0.0125	-125
6	39.9829	-0.0125	-125
7	49.97862	-0.0125	-125
8	59.97435	-0.0125	-125

Figure 4.37

4.40 Go to File > Save As.. and save the excel sheet as a ‘Text tab delimited’ file in your Datasets/Scanned_Seismic/Bathy_Along_Profile folder, with the same name as the table in your GIS project.

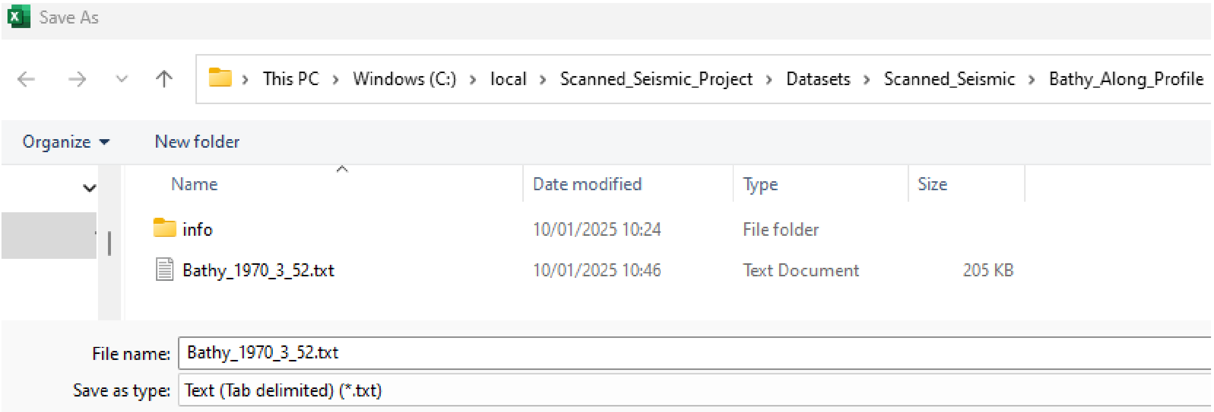


Figure 4.38

4.41 Go back to your GIS project and open the map for the scan you are working on (e.g., the Sparker_1970_3_52 map). Click on the Map tab from the top ribbon and then use the drop-down under ‘Add Data’ to select ‘XY Point Data’

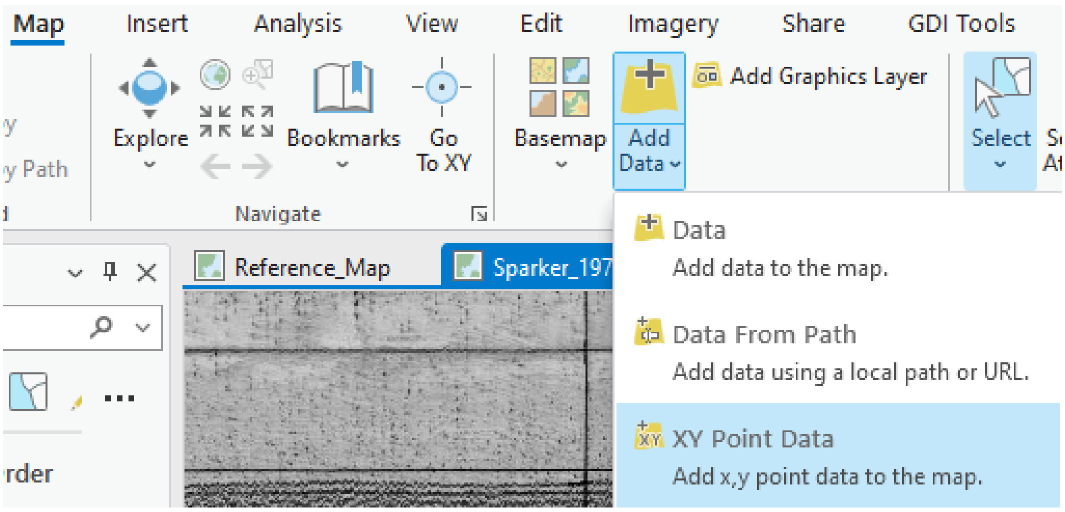


Figure 4.39

4.42 In the ‘XY Table To Point’ dialogue, use the folder icon next to the ‘Input Table’ field to select the text file you’ve just created (you may have to refresh the explorer window). Use the folder icon next to the ‘Output Feature Class’ field to navigate to the same folder where you saved your text file, then create a new folder in that space called ‘Shapefiles’ (this is just to keep your folder space well-organised), then save with the same name as the initial text file, but add the suffix ‘_topoint’.

Select ‘FIRST_DIST’ as the ‘X Field’ and ‘Ref_Elev’ as the ‘Y Field’. Change the Coordinate System to British National Grid (or ‘Same as current map’ assuming you are on your map for the scan). Click Run.

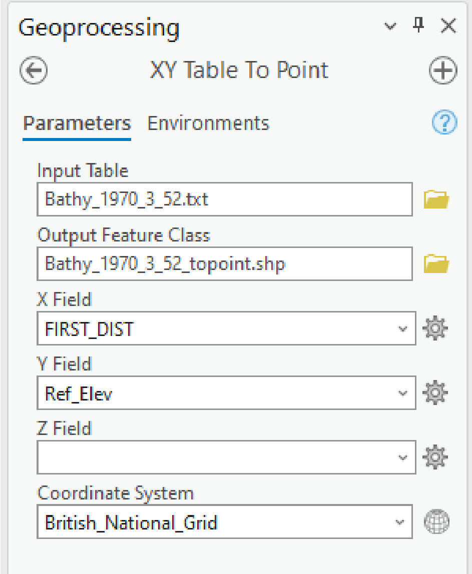


Figure 4.40

4.43 You should see that the points have been imported and that they sit approximately on the seabed on your spatially referenced scanned image (you might want to alter the symbology to make the position of the points clearer). **If they look like they are flipped the wrong way round compared to your scanned data – see below for the fix.**

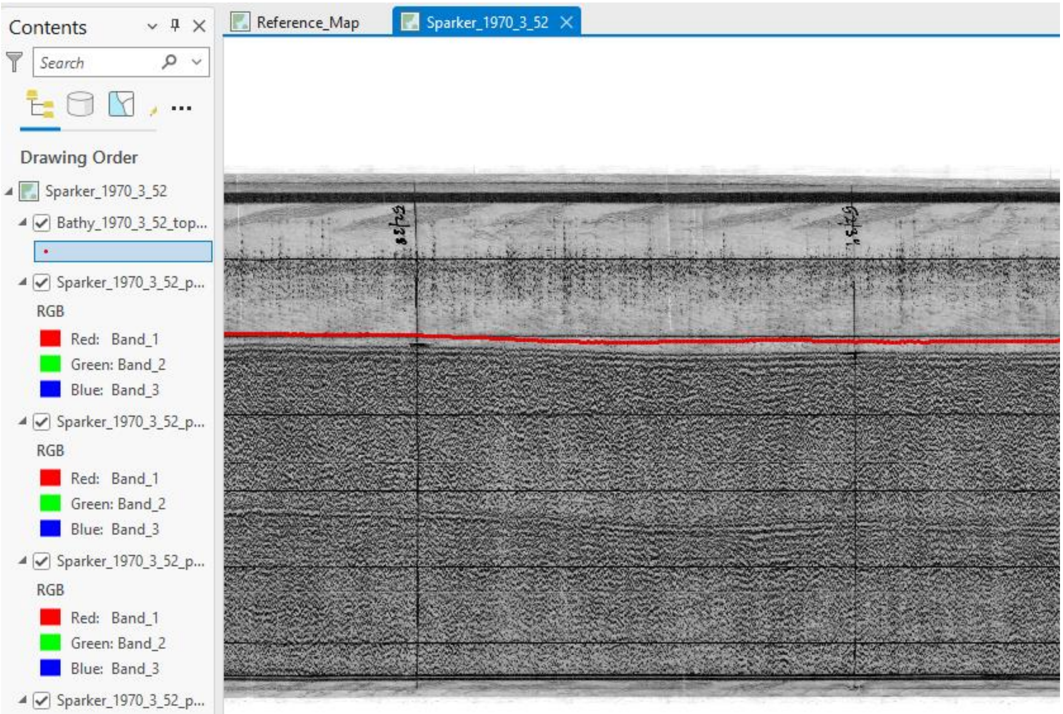


Figure 4.41

4.44 The Stack Profile tool returns data where 'FIRST_DIST' from the start point of the line that was selected in the process, this depends on the way the line was drawn (or calculated in ArcGIS if generated from coordinate points). This means that if the line was 'drawn' from west to east instead of east to west, the points may appear flipped compared to your georeferenced scan. See example in Figure 4.42

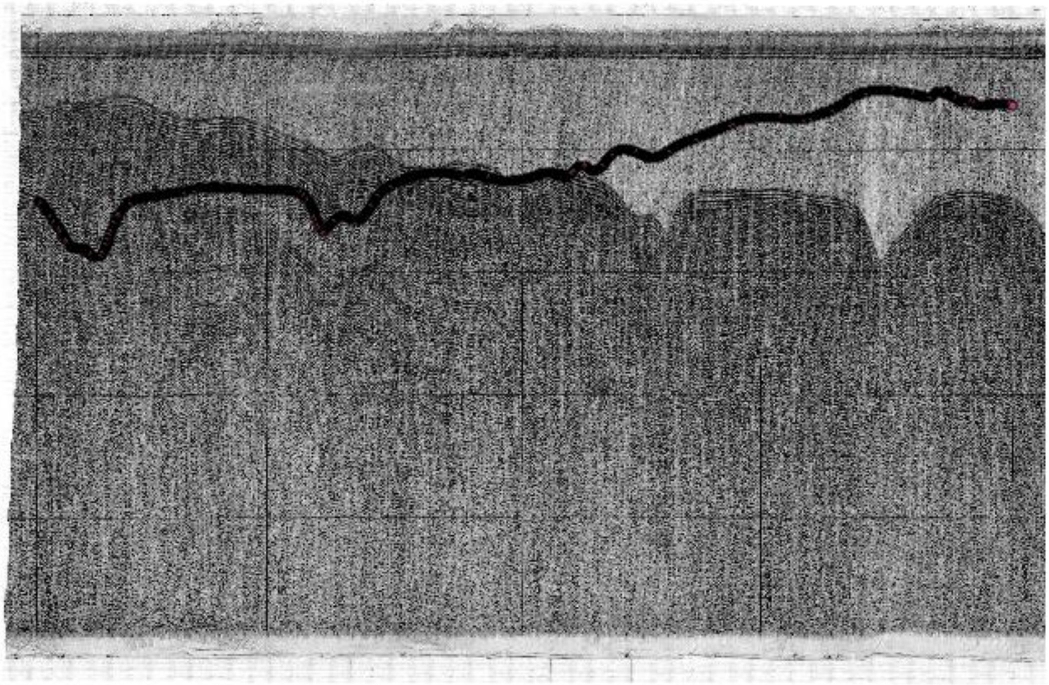


Figure 4.42

4.45 To correct the flip, reopen the table you created in steps 4.39 and 4.40 for the extracted bathymetry. In a 4th column, which you can just call 'X' you want to calculate the reverse of the 'FIRST_DIST' values. Do this by either finding the max value of the 'FIRST_DIST' column, or using that cell in the formula as depicted in Figure 4.43. Check that the values in the X column make sense – so that the last value is 0. Then copy and paste in the same place, but as values only. Save this as a new tab delimited text file, e.g., with the tag '_corrected'.

SUM | fx | =7936.132402-A2

	A	B	C	D	E
1	FIRST_DIS	FIRST_Z	Ref_Elev	X	
2	0	-0.1424	-1424	=7936.132402-A2	
3	3.999796	-0.1428	-1428	7932.133	
4	7.999591	-0.1429	-1429	7928.133	
5	11.99939	-0.143	-1430	7924.133	
6	15.99918	-0.1434	-1434	7920.133	

SUM | fx | =$A$1987-A2

	A	B	C	D	E
1	FIRST_DIS	FIRST_Z	Ref_Elev	X	
2	0	-0.1424	-1424	-A2	
3	3.999796	-0.1428	-1428	7932.133	
4	7.999591	-0.1429	-1429	7928.133	
5	11.99939	-0.143	-1430	7924.133	
6	15.99918	-0.1434	-1434	7920.133	

Figure 4.43

4.46 Now, repeat steps 4.41 and 4.42, but use this corrected table as the input and select ‘X’ as the ‘X Field. You should see that the bathymetry points have flipped to the same orientation as your georeferenced scan. Note that you may still have offsets, as in the example shown below in Figure 4.44. These offsets probably relate to errors in labelling of the paper records, you can shift/stretch the scan to match the bathymetry to ‘correct’ for this.

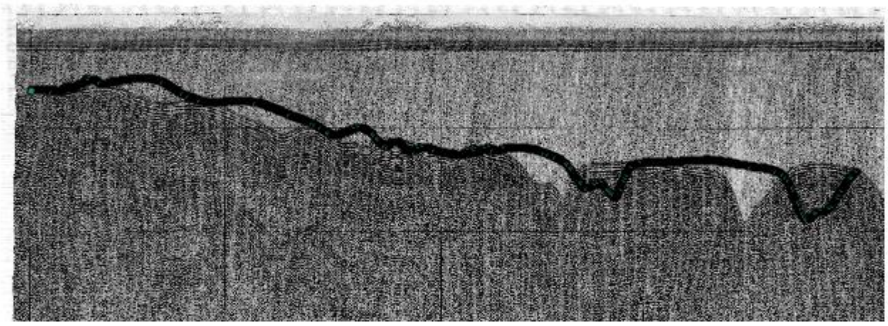


Figure 4.44

Note that the general geometry should fit the seabed reflection in your scan, but there will be deviations. Most notably that the seabed is likely mobile and there is a large time gap between when the seismic data and the bathymetry data were acquired. Additionally, there will be some errors introduced from how straight/wiggly your seismic line is in map view**. However, there are two systematic errors that can be corrected for.**

4.47 If there is what looks like a large lateral offset as in Figure 4.44 (if not then skip this step), then click on the scan in the table of contents, then go to the ‘Imagery’ tab and click on ‘Georeference’. Open the ‘Control Point Table’. Then use a process of trial and error to edit the ‘Map X’ values until you get a good match between your scan and the bathymetry (don’t edit the ‘Map Y’ values – see below for this correction). Stick to round numbers e.g., to nearest 100 map units. You can choose a different amount of shift for the left- and right-hand control points, but make sure that the Map X values are the same for the **same shot point position** (where they are aligned vertically). Save your edits. Close the Georeferencing toolbar.

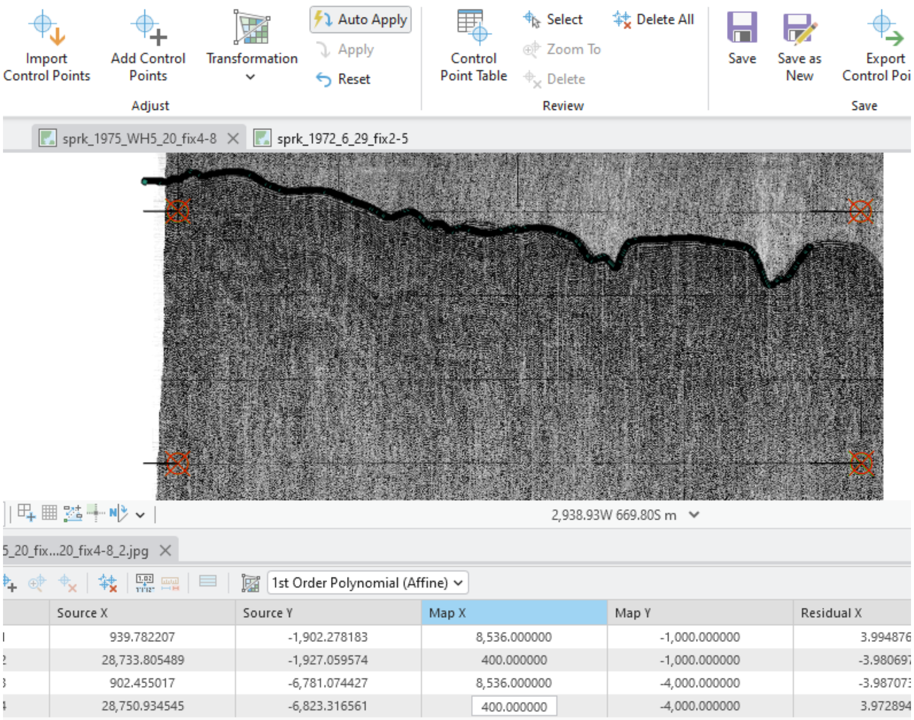


Figure 4.45

4.48 There may also be a consistent offset where there is a difference between the LAT datum of the bathymetry and the datum used for the seismic – this difference we can correct for.

4.49 Use the measure tool in the inquiry section of the Map tab to measure the vertical distance between the seabed points you just imported and the seabed reflection on the georeferenced scan. Measure at a number of different places along the scan and make a judgement about what a general average offset value is.

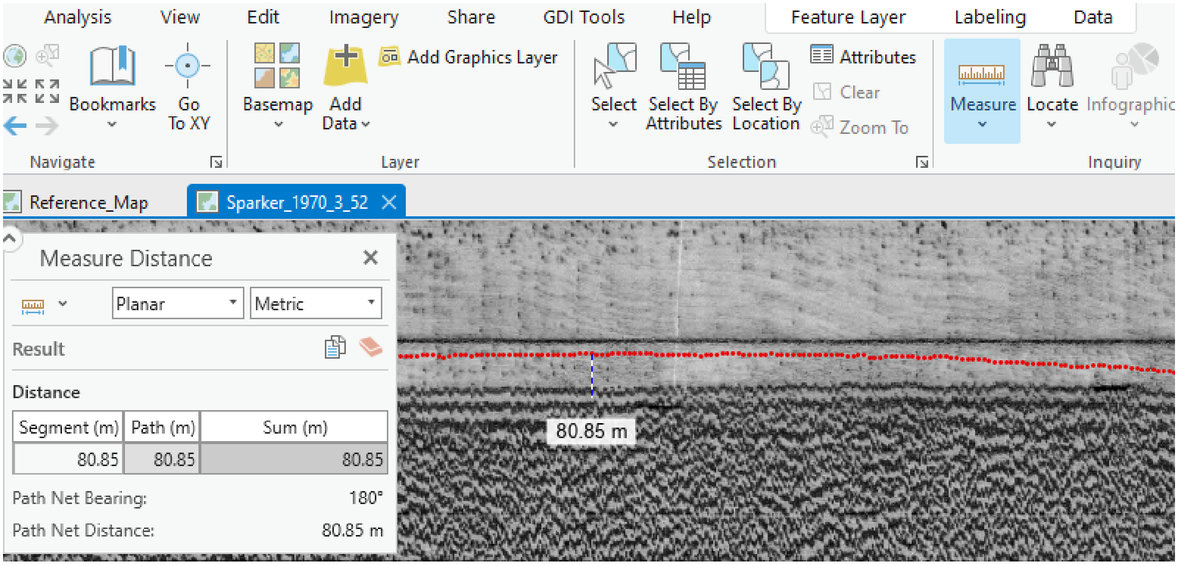


Figure 4.46

4.50 Once you've determined an approximate value, you'll need to alter the spatial reference for the scanned seismic. For the example here, after a few measurements along the profile, the general vertical offset is around 80 map units – referring back to what we have done in this work flow, that corresponds to an offset of 8 milliseconds two-way-time.

To make the correction, click on one of the scan jpegs in your table of contents, go to the 'Imagery' tab from the top ribbon, then click on 'Georeference'. Click on 'Control Point Table'. This will open a table at the bottom of the map window showing the X and Y values you entered for the grid line intersections for the scan. Change all the values in the 'Map Y' field by the value you determined in step 4.49 (make sure you change the values in the right direction to ensure your scanned image shifts towards the bathymetry points). Save your edits. Close the Georeferencing toolbar (you need to do this so you can edit the georeferenced you have for any other jpegs for the scan).

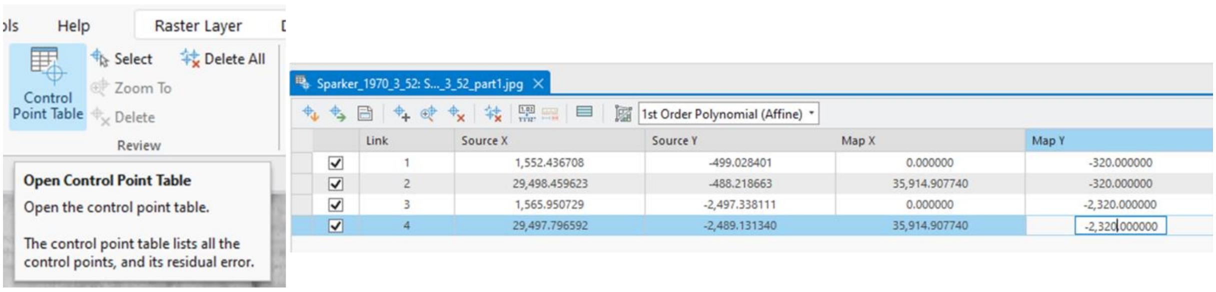


Figure 4.47

4.51 Repeat step 4.50 for each jpeg you have for the scan. Check that your grid lines all line up and that no unexpected warping has happened to your image – if you notice something odd, you may have accidentally entered a value for the Map Y that wasn't consistent with the alteration you want to apply. **Make sure you apply the same alteration/shift to all your jpegs that make up one scanned record (if you had to segment) even if some do not have any overlap with the bathymetry points**.

4.52 You should now see that your scanned image sits nicely aligned with the bathymetry points.

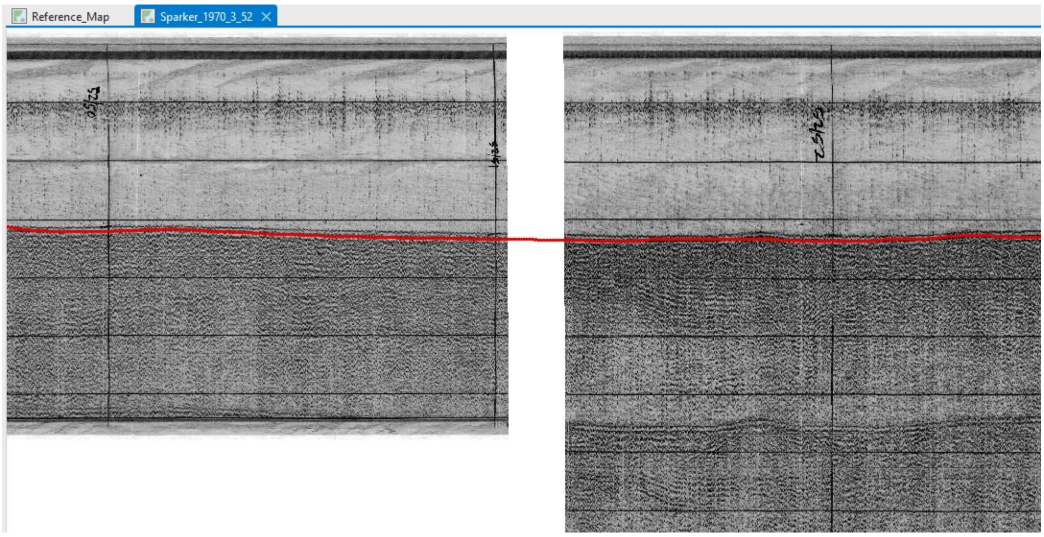


Figure 4.48

The scanned seismic is now ready for interpretation! If you prefer however, you may want to repeat the process from section 3 up to this step, to add more maps with spatially referenced scans before you get started. Note, many of the steps, particularly those that relate to creation of new folder, can be skipped now that you have completed the process for the first scan.

5 MAKING INTERPRETATION PICKS FROM THE SCANNED SEISMIC DATA

5.1 Adding Borehole Information

Once the scanned data has been prepared with a pseudo-spatial reference, you can being making an interpretation of the geology. To assist with this, you may want to consult the borehole records from the BGS Offshore Geoindex. Access the offshore geoindex here: https://www.bgs.ac.uk/map-viewers/geoindex-offshore/.

Note that not all seismic lines will intersect with a borehole, and that many of the borehole records may also be legacy scans.

5.1 On the Geoindex, turn on the ‘Borehole: Activity & Scan’ layer under ‘Sample Data’ along with the ‘Seismic Reflection’ layer. Find the seismic line that relates to the scan you want to work on by left clicking on the lines. Then find where the line intersects a borehole record. Click on the borehole point and it will open a small information box, which may have a link to a PDF, which you can open to see what the borehole records contain.

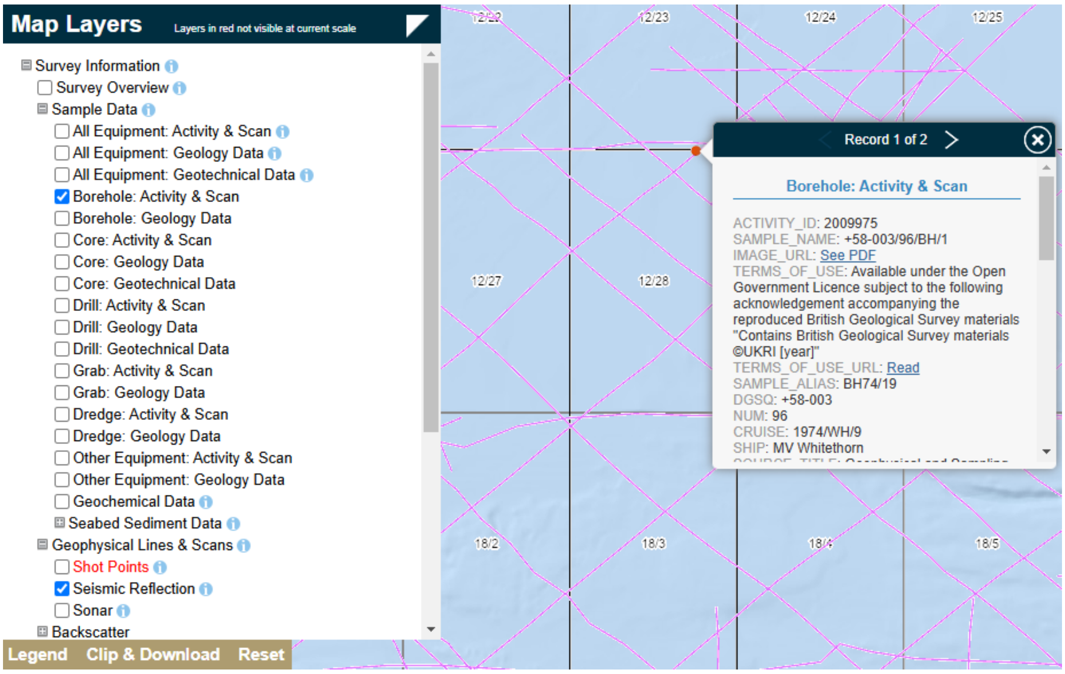


Figure 5.1

5.2 You may also want to download a shapefile for the borehole locations to add to your GIS project. Turn off the Seismic Reflection layer on the Geoindex, and turn on the ‘Borehole: Geology Data’ so you have both the ‘Borehole: Activity & Scan’ and ‘Borehole: Geology Data’ layers turned on. Follow the same process outlined in steps 2.6 to 2.10 to download the data.

5.3 In your Datasets folder, create a new folder called ‘Boreholes’, and create another folder within this one called ‘Shapefiles’. Extract the data you downloaded to this shapefiles folder.

5.4 Go to your GIS project and click on the Reference_Map. Navigate to the Datasets/Boreholes/Shapefiles folder in the Catalog Pane (you may need to right-click on the Datasets folder and Refresh). Drop the two shapefiles (not the layer files into your map).

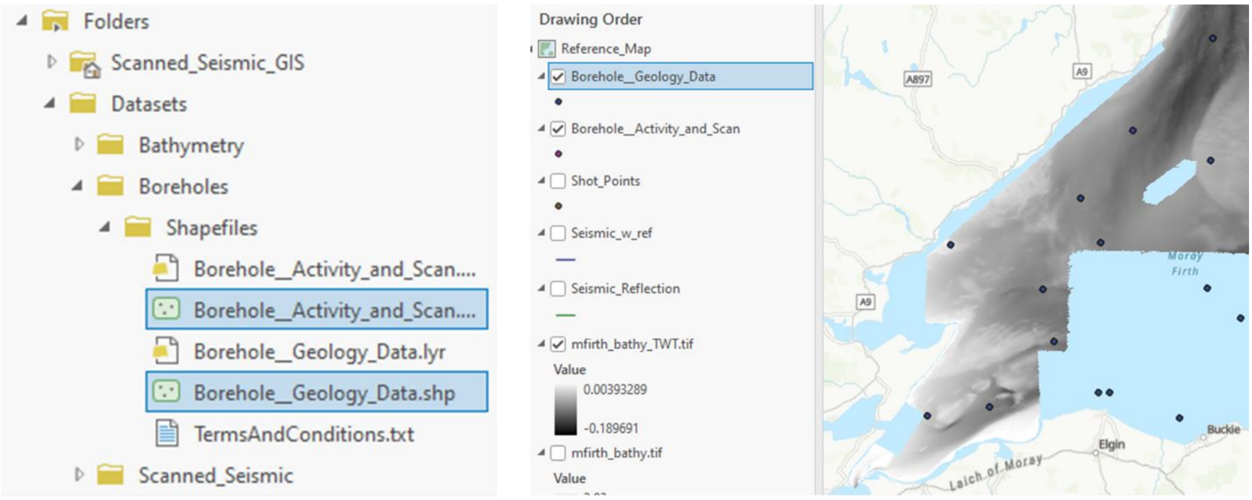


Figure 5.2

5.5 You can use your ‘Seismic_w_ref’ shapefile layer, which you created to show the position of the scan(s) you have been working on to see where boreholes are intersected.

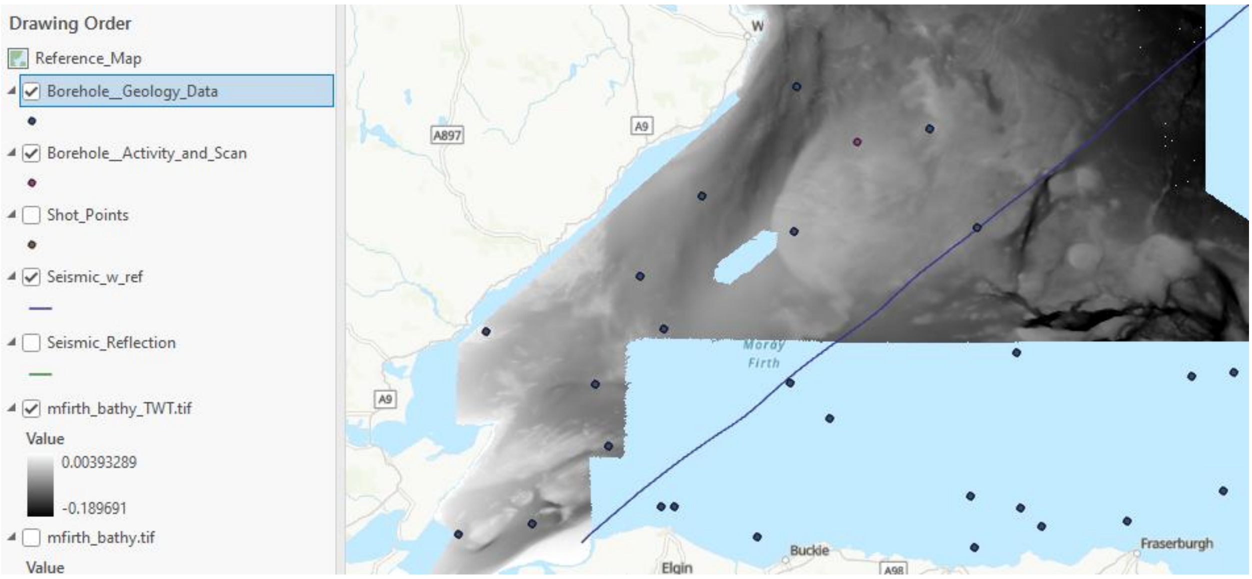


Figure 5.3

5.6 Turn off the ‘Borehole__Geology_Data’ shapefile layer, leaving the ‘Borehole__Activity_and_Scan’ shapefile layer turned on. Use the ‘Explore’ option from the Map tab to click on the point that relates to a borehole you want to query. Scroll down in the info box that appears to the X_BNG and Y_BNG fields and make a note of the values. Also make a note of the ‘WATER_DEPT’ field value.

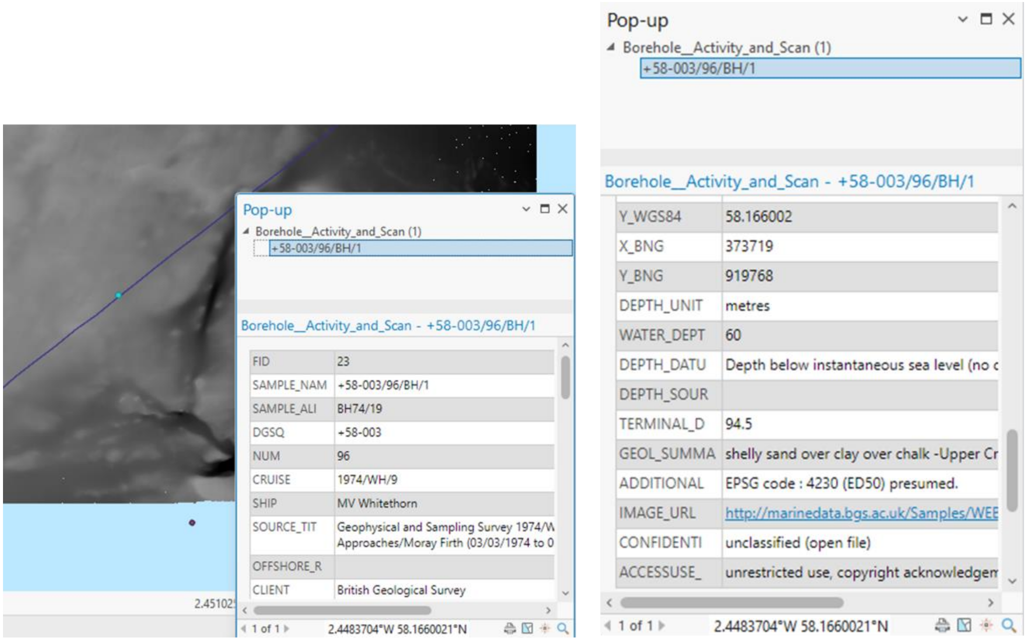


Figure 5.4

5.7 In this case the values are: X_BNG 373719; Y_BNG 919768; and WATER_DEPT 60. Note that the water depth may not be corrected for metres below lowest astronomical tide (mLAT), but this can be dealt with later.
Using the same method as in step 4.17. We can calculate the offset of the borehole from the first shot point of the seismic line that was spatially referenced, so we can determine how far along the profile the borehole sits (approximately – note that the borehole may not sit directly on the seismic line). In this case the formula would be:
$((373719 - 309307.5943)^2 + (919768 - 868540.43212)^2)^{1/2}$ = **82298.8025**

This provides an X value in distance along profile, which we can use to add borehole information to the GIS map with the spatially referenced scan.

5.8 In the Pop-up for the borehole point that opens when you query it with the explore tool, scroll down to the ‘IMAGE_URL’ field and click on the link. The scanned PDF (if it exists) will open in your default browser.

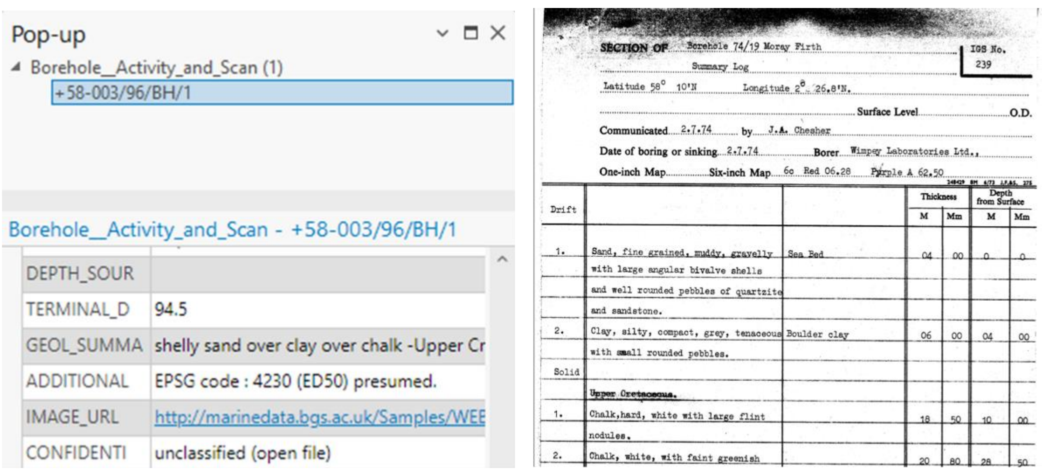
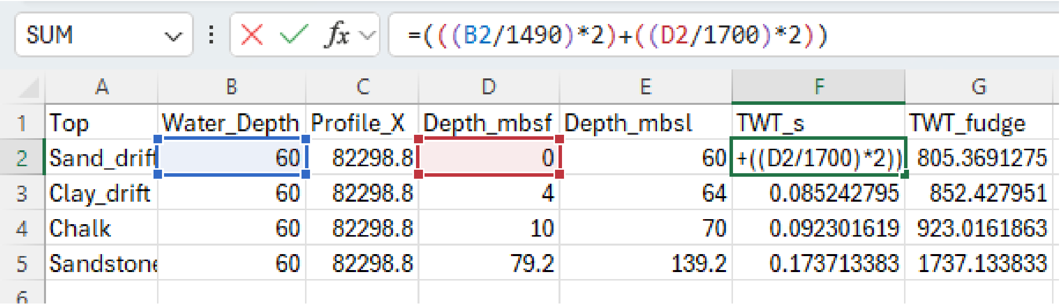


Figure 5.5

5.9 Open a blank Microsoft Excel document where you can transfer selected geological information. You may want to follow a similar format to the example below. Use the formula shown below to convert the depth below seafloor into two-way-time. This assumes a constant velocity below seabed of 1700 ms^{-1}. Then apply the x10000 'fudge' factor to another column. Once you are happy with the values in the TWT and TWT_fudge columns, copy and paste in the same cells as values only. **Change the fudge values to negatives.**



SUM | =(((B2/1490)*2)+((D2/1700)*2))

	A	B	C	D	E	F	G
1	Top	Water_Depth	Profile_X	Depth_mbsf	Depth_mbsl	TWT_s	TWT_fudge
2	Sand_drift	60	82298.8	0	60	+((D2/1700)*2))	805.3691275
3	Clay_drift	60	82298.8	4	64	0.085242795	852.427951
4	Chalk	60	82298.8	10	70	0.092301619	923.0161863
5	Sandstone	60	82298.8	79.2	139.2	0.173713383	1737.133833

Figure 5.6

5.10 Go to File > Save As.. and save the excel sheet in your Datasets/Boreholes folder with a name that includes the name of the borehole, and a reference to the seismic line (because the X values relate to a specific spatial reference), save as a Text (tab delimited) file. For example: CL1970_3_52_58-003-96-BH-1.txt.

5.11 Close the Excel sheet and go back to your GIS project and the relevant Scan map. From the 'Map' tab, use the drop-down under 'Add Data' to select 'XY Point Data'. Use the folder icon next to the 'Input Table' to select the text file you created (you may need to right-click and refresh the folder space). Use the folder icon next to the 'Output Feature Class' field to navigate to your Datasets/Boreholes/Shapefiles folder and save the file with the same name as the input table, but if there is character space you could add the suffix '_tops'. Select 'Profile_X' as the 'X Field' and 'TWT_fudge' as the 'Y Field', change the coordinate system to 'Current Map' or British National Grid. Click Run.

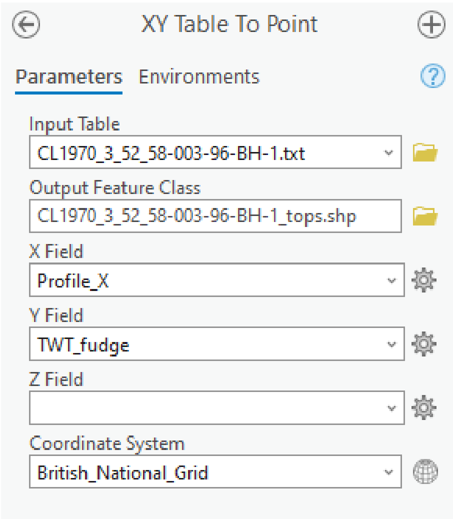


Figure 5.7

5.12 You should see that the points have plotted nicely on your seismic section. You can click on the symbol icon under the name of this points layer in the table of contents to change it to something that will be more visible.

You can also label the points with the information you included in the spreadsheet. Right-click on the layer in the table of contents and go to ‘Labelling Properties’. Double click on ‘Top’ under fields so that the Expression box shows ‘$feature.Top’. Click Apply. You can also change the label symbol using the symbol tab (you might want to increase the font size and choose a bright colour).

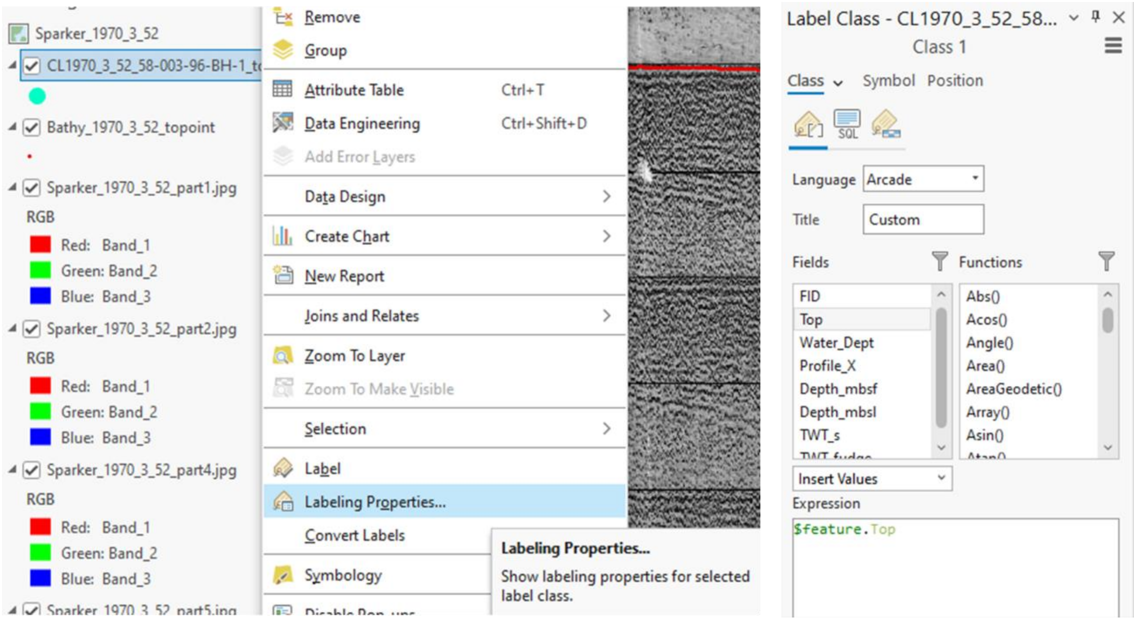


Figure 5.8

5.13 Right click again on the layer in the table of contents and click on ‘Label’ (see above). You should see that the points are now labelled with the geological information you included, so that the points represent the top of geological layers.

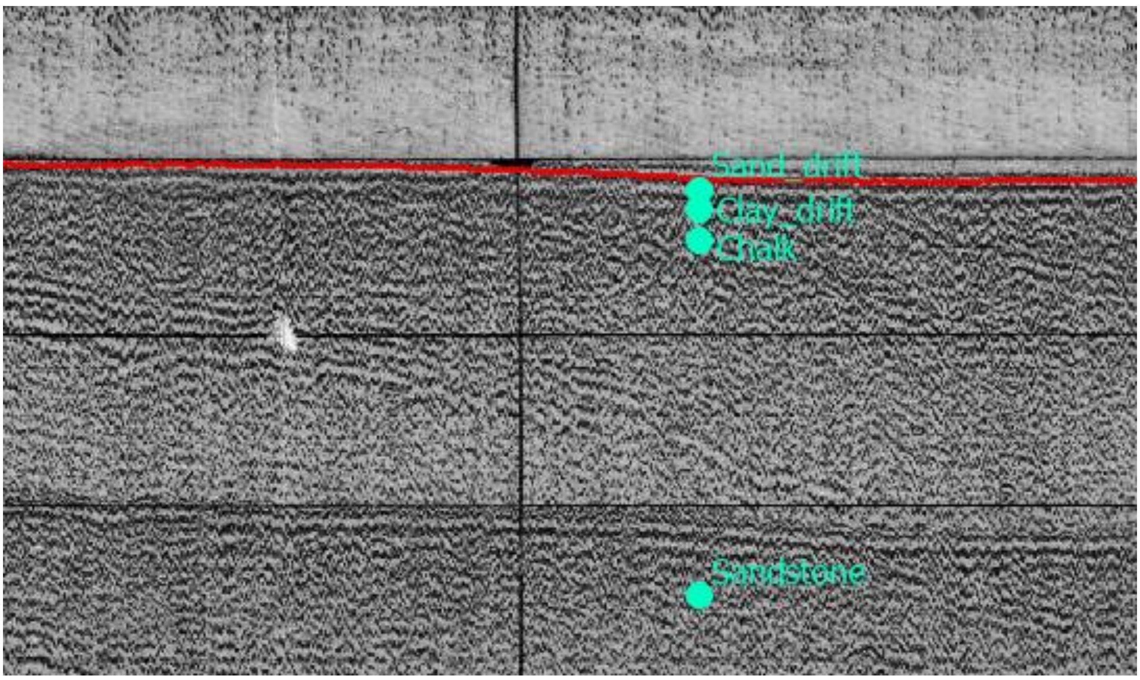


Figure 5.9

5.14 If the geological layer that starts at the seabed shows an offset from your bathymetry points that you deem to be significant, you can correct for this. First, use the measure tool to determine what the offset is.

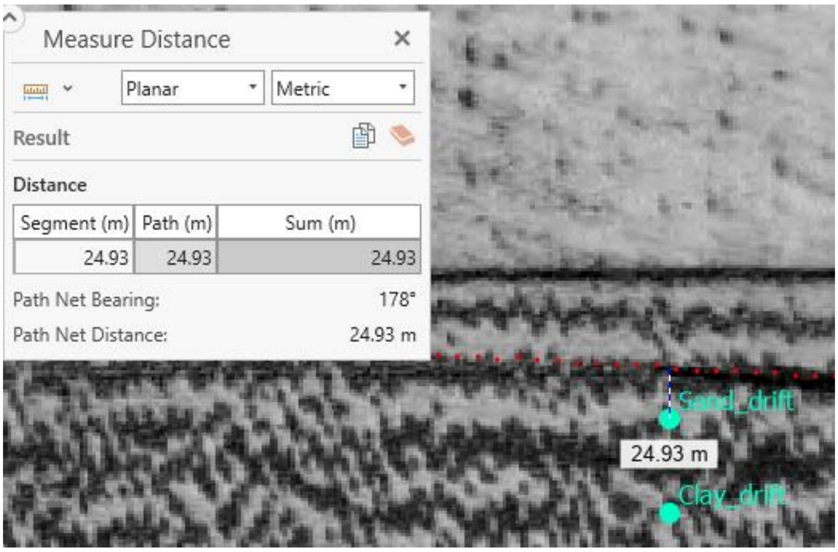


Figure 5.10

5.15 Go to the 'Edit' tab from the top ribbon and use the 'Select' tool to select one of the points, then click on 'Modify' this will bring up a list of edit options on the right-hand side of ArcPro.

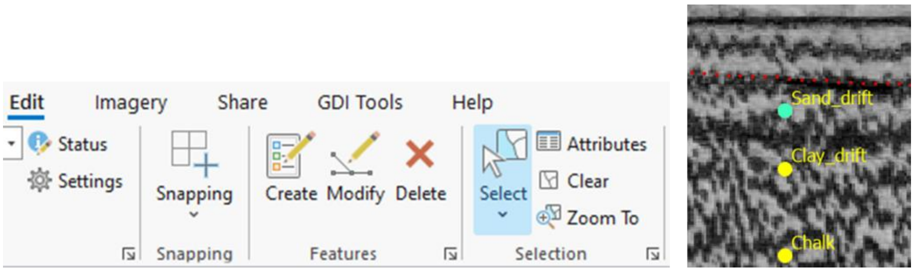


Figure 5.11

5.16 Select the 'Move To' tool. This will bring up a dialogue that shows the X and Y position of the point that you have selected. Here, you can modify the Y value based on your measurement in step 5.14. In the example, the original measurements was ~-805, and we want to shift the point up by ~25 map units, so the value to enter is -780. When happy, click on 'Move To' at the bottom of the dialogue. This will shift the point to the seabed.

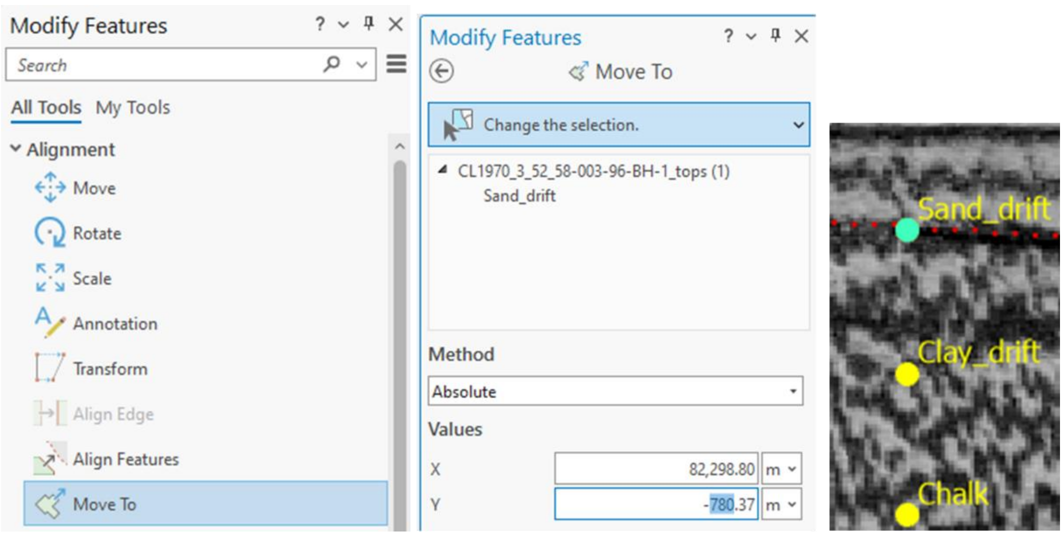
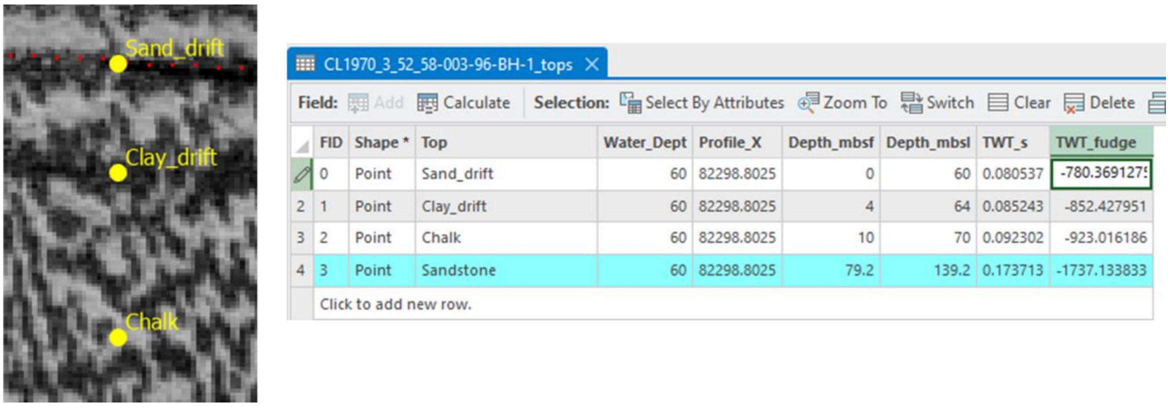


Figure 5.12

5.17 It's important to then apply the same vertical shift to all your borehole points using the same tool. You may also want to change the values in the table of attributes, but this is not necessary.



	FID	Shape *	Top	Water_Dept	Profile_X	Depth_mbsf	Depth_mbsl	TWT_s	TWT_fudge
	0	Point	Sand_drift	60	82298.8025	0	60	0.080537	-780.369127
2	1	Point	Clay_drift	60	82298.8025	4	64	0.085243	-852.427951
3	2	Point	Chalk	60	82298.8025	10	70	0.092302	-923.016186
4	3	Point	Sandstone	60	82298.8025	79.2	139.2	0.173713	-1737.133833

Figure 5.13

5.2 Horizon Interpretation

Now you have some borehole information to aid your seismic interpretation. The next step is to create a line feature for a horizon interpretation.

5.18 Go to your Scanned_Seismic_Project folder space in windows explorer and create a new folder called 'Horizon_Interpretations'.

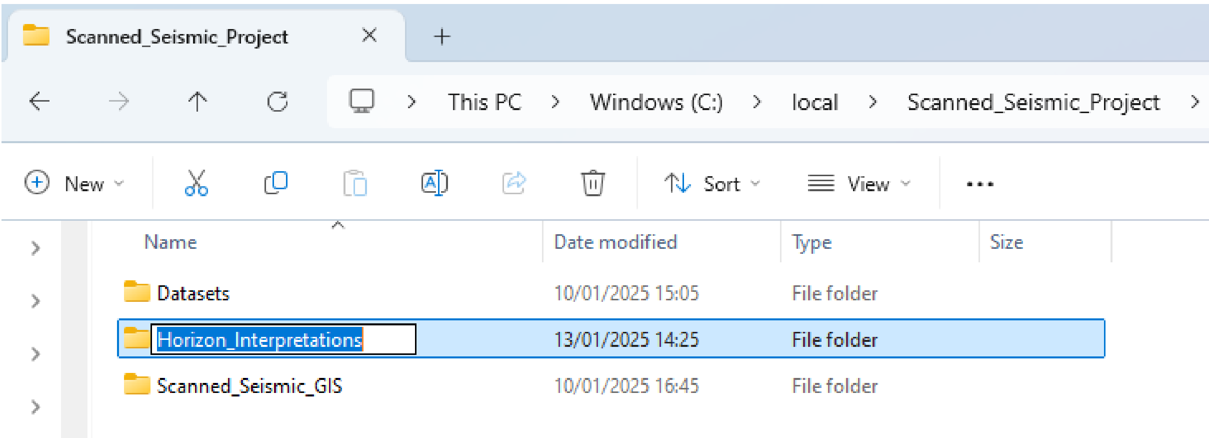


Figure 5.14

5.19 In your GIS project, find the folder you've just created in the Catalog Pane. You may have to right-click on 'Folder' and 'Add Folder Connection'.

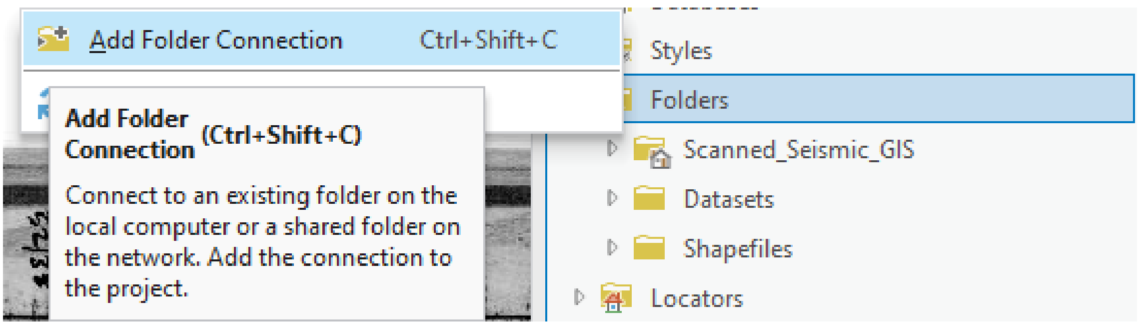


Figure 5.15

5.20 Right-click on the ‘Horizon_Interpretations’ folder and go to ‘New’ > ‘Shapefile’.

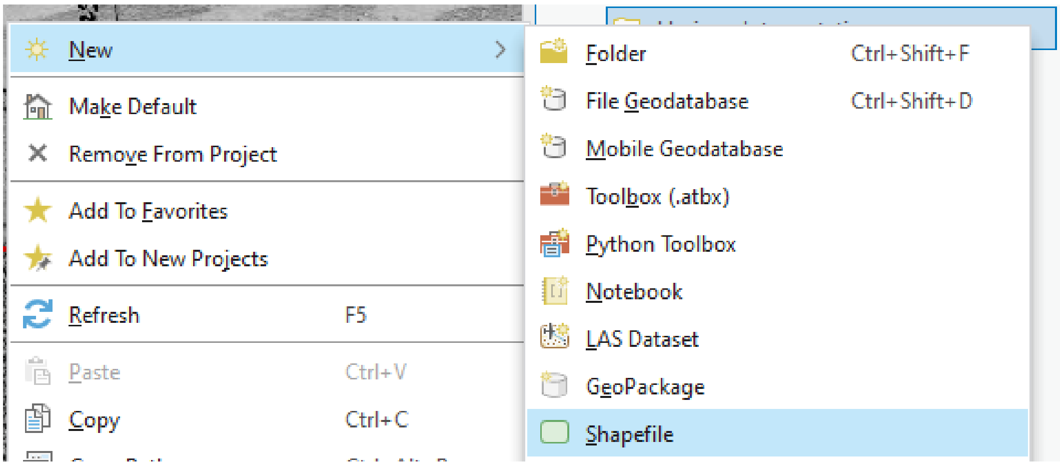


Figure 5.16

5.21 In the Create Feature Class dialogue, add a name for the horizon you want to interpret – for example ‘Top_of_Bedrock’ (note you probably want to include some reference to the cruise line name for the seismic), change the ‘Geometry Type’ to ‘Polyline’, change the ‘Coordinate System’ to ‘Current Map’ (or British National Grid). Click Run. The new feature will have appeared in the table of contents. Click on Save in the ‘Manage Edits’ section of the Edit tab.

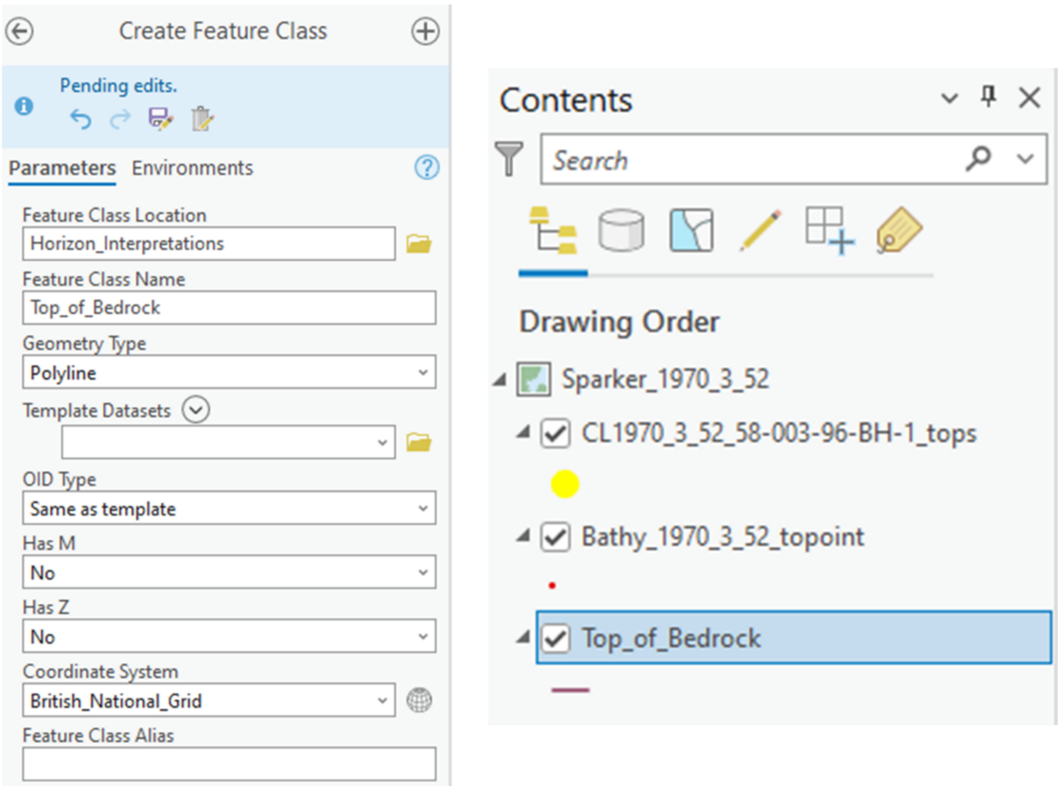


Figure 5.17

5.22 To make picks for your interpretation, from the Edit tab, click on ‘Create’ from the ‘Features’ section. The ‘Create Features’ pane appears on the right, where you can see the editable layers. Select your horizon feature, and the picking/drawing options will be displayed. You probably will only need the ‘Line’ option.

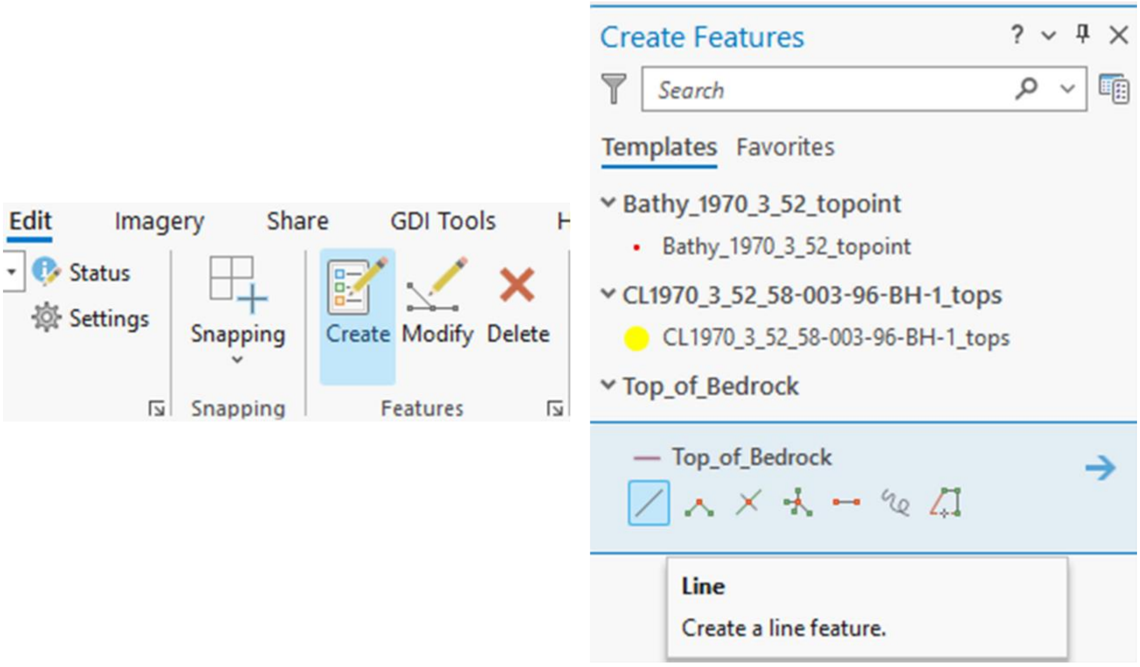


Figure 5.18

5.23 You can now make horizon picks in the map window. You can start and create as many new lines as part of the same feature as you feel you need – but these will have to be merged into one feature later. Make sure that your lines do not overlap, small gaps between them are ok.

5.24 If required, you can go to the Edit tab, click on ‘Modify’ and then choose ‘Edit Vertices’ to move picks if you want to make alterations.

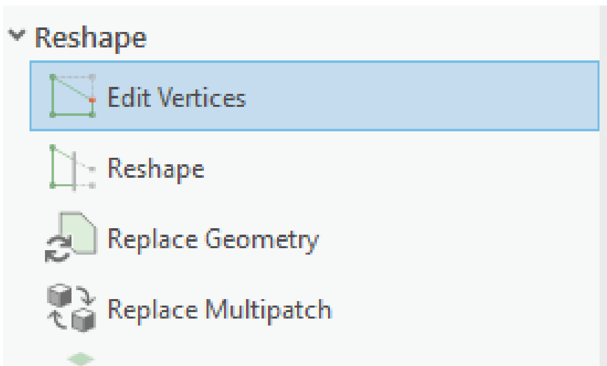


Figure 5.19

5.25 You can periodically save your edits using the 'Save' button under 'Manage Edits'.

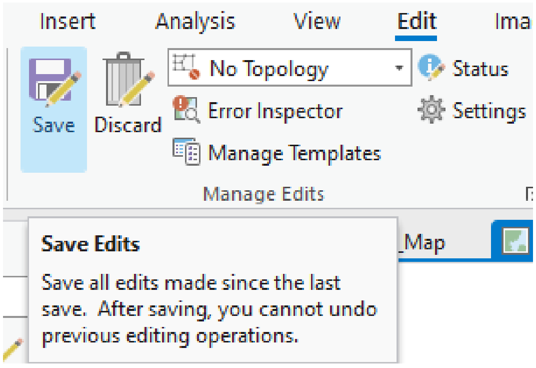


Figure 5.20

5.26 If you have multiple line segments, use the 'Select tool' to select all of the lines that relate to the horizon you are interpreting. From the 'Tools' section of the 'Edit' tab, select 'Merge'. Click 'Merge' at the bottom of the dialogue pane that opens.

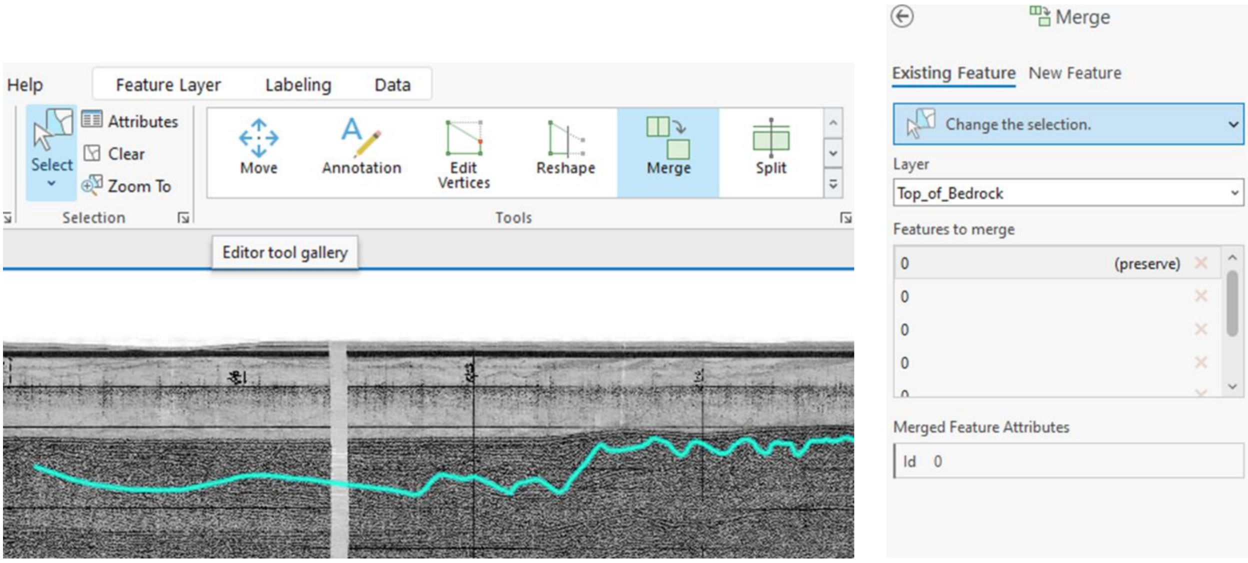


Figure 5.21

5.27 When you open the attributes table for your horizon feature, you should see that there is only one line feature within it. Remember to save your edits.

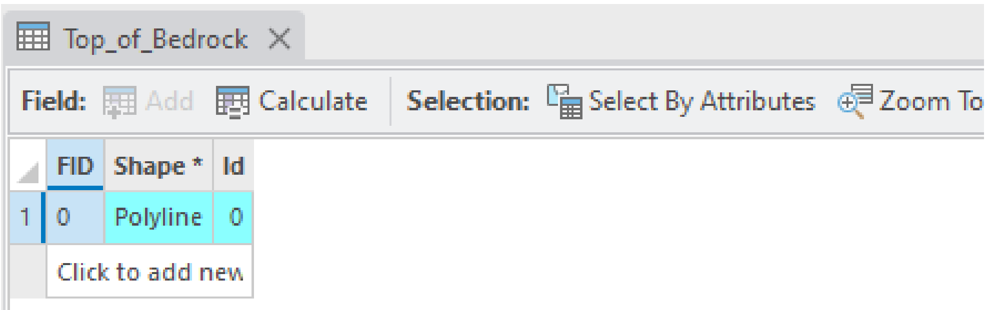


Figure 5.22

6 EXTRACT PICKS AND CONVERT TO GEOSPATIAL DATA

6.1 Once happy with the interpretation, the next step is to begin extracting the data. To do this go to ‘Tools’ from the ‘Analysis’ tab, then search for ‘Feature Vertices To Points’ and open the tool.

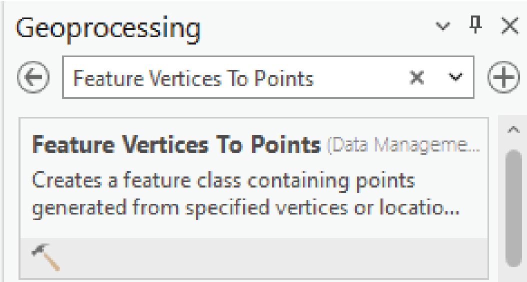


Figure 6.1

6.2 Under ‘Input Features’ select your interpreted horizon, under ‘Output Feature Class’ use the folder icon to navigate to your ‘Horizon_Interpretations’ folder, and save with the same name, but add the suffix ‘_p’ for points. Make sure that ‘Point Type’ is set to ‘All vertices’. Click Run. The points will appear in the table of contents.

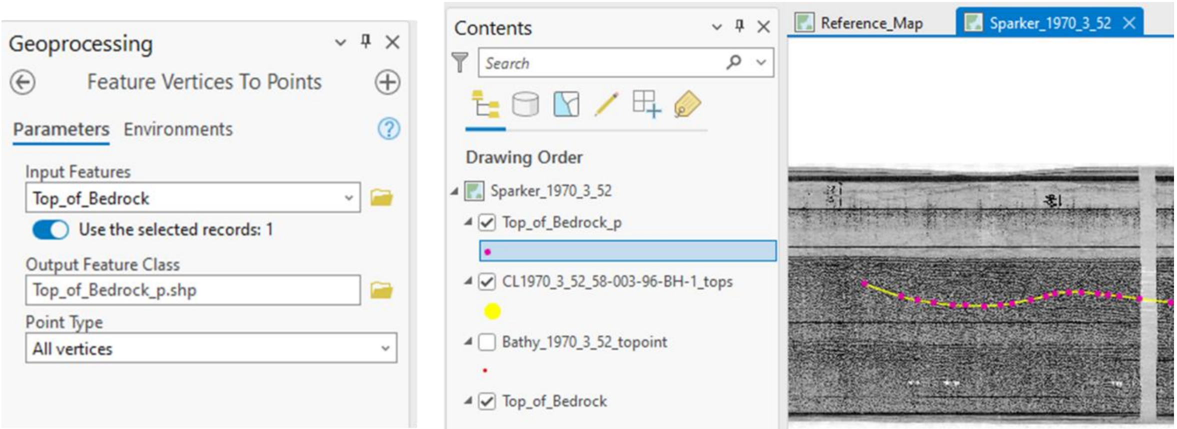


Figure 6.2

6.3 Go back to ‘Tools’ from the ‘Analysis’ tab and this time search for ‘Add XY Coordinates’ and open the tool. Under ‘Input Features’ select the points layer you have just created. Before you run the tool, go to the ‘Environments’ tab within the tool and change the ‘Output Coordinate System’ to British National Grid.

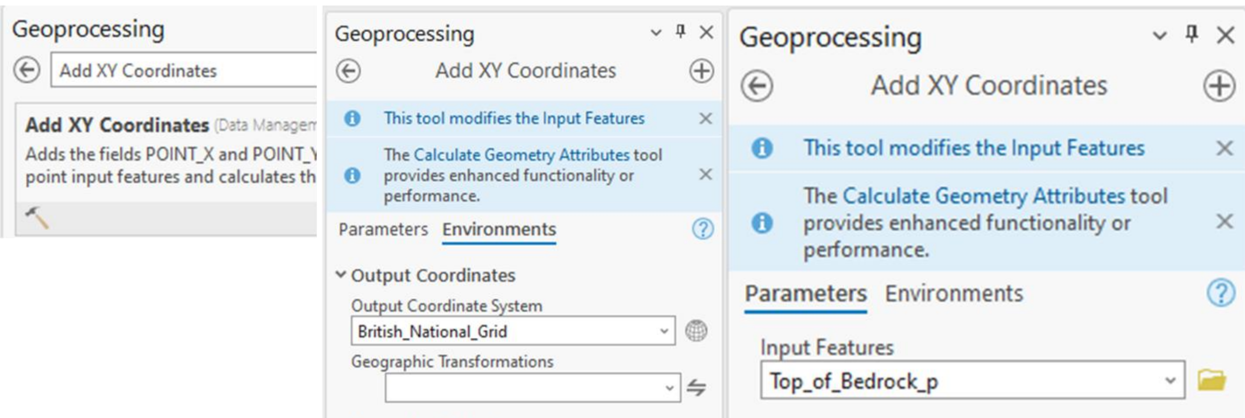
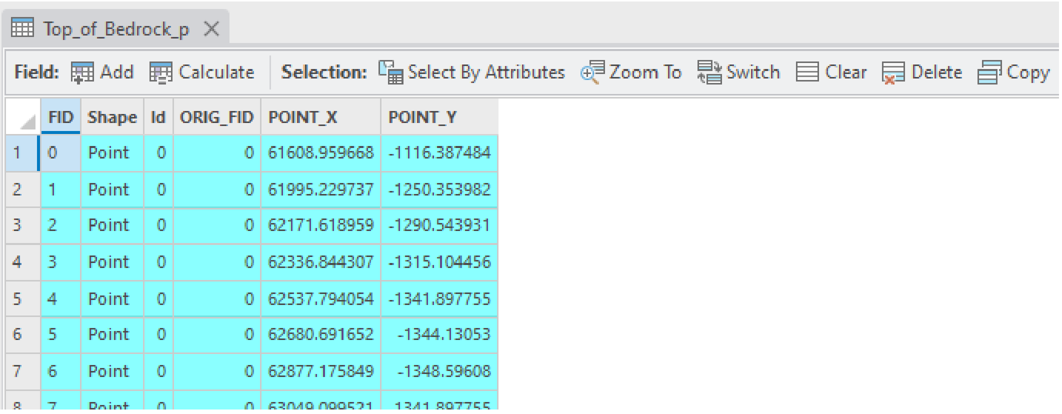


Figure 6.3

6.4 Open the attributes table for the points feature and you should see that there is now a ‘POINT_X’ and ‘POINT_Y’ field. Click in the grey space to the right of the table and use Ctrl+A on your keyboard to select all, then click on ‘Copy’.

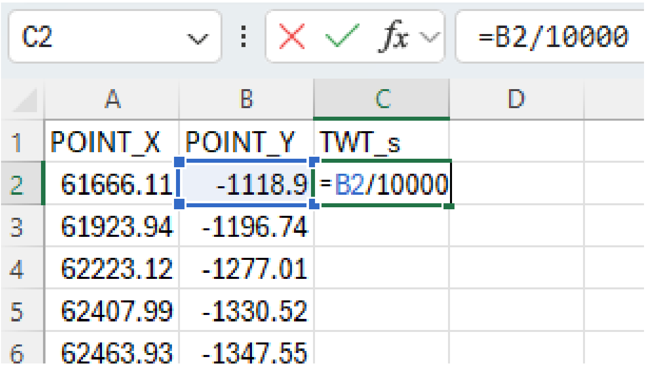


	FID	Shape	Id	ORIG_FID	POINT_X	POINT_Y
1	0	Point	0	0	61608.959668	-1116.387484
2	1	Point	0	0	61995.229737	-1250.353982
3	2	Point	0	0	62171.618959	-1290.543931
4	3	Point	0	0	62336.844307	-1315.104456
5	4	Point	0	0	62537.794054	-1341.897755
6	5	Point	0	0	62680.691652	-1344.13053
7	6	Point	0	0	62877.175849	-1348.59608

Figure 6.4

6.5 Open a blank Excel document and paste the data. Delete all of the columns except ‘POINT_X’ and ‘POINT_Y’. The next step is to convert this data into X, Y, Z format, where the Z column is two way time in seconds. The first and easiest step is to convert the POINT_Y field to Z.

6.6 The ‘fudge’ in earlier steps, to ensure that a useful aspect ratio for the vertically exaggerated seismic is maintained, was to use 100 m vertically for 10 ms. To convert back to time in seconds then simply divide the POINT_Y column by 10000 (10 for the fudge, 1000 for milliseconds to seconds).



	A	B	C	D
1	POINT_X	POINT_Y	TWT_s	
2	61666.11	-1118.9	=B2/10000	
3	61923.94	-1196.74		
4	62223.12	-1277.01		
5	62407.99	-1330.52		
6	62463.93	-1347.55		

Figure 6.5

6.7 Converting the POINT_X into the ‘true’ X and Y coordinates is more complicated. The POINT_X values is the distance in metres from the first shot point location along an arbitrary straight line. We need to determine some directionality of the line – essentially the reverse of the calculation in step 4.17. Get the X_BNG and Y_BNG coordinates of the first and last shot point for your seismic line.
For the example here:

First shot point X_BNG 309307.5943, Y_BNG 868540.43212

Last shot point X_BNG 429947.30097, Y_BNG 965373.54592

6.8 We need to work out the change in X_BNG per m along the straight line and the change in Y_BNG per m along the straight line. First determine the change in X_BNG and Y_BNG from the first to last shot point.

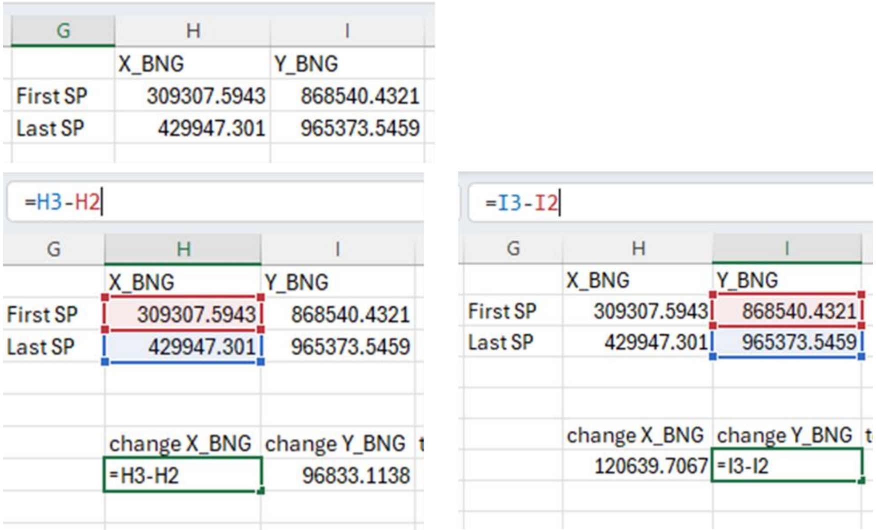


Figure 6.6

6.9 Now calculate the total length along the line using the formula $\sqrt{(\Delta x)^2 + (\Delta y)^2}$ (same as in step 4.17).

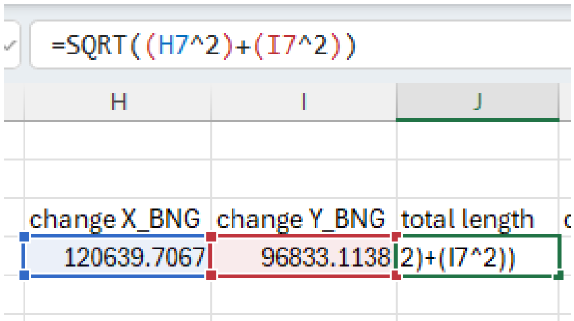


Figure 6.7

6.10 Then divide the change in X_BNG and Y_BNG by this total distance.

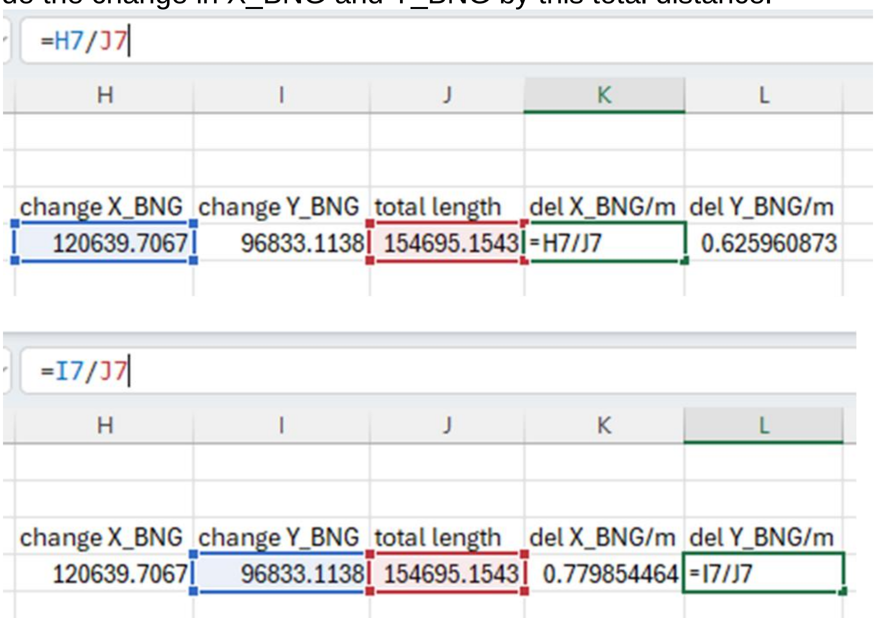


Figure 6.8

6.11 In additional columns, now calculate the X_BNG and Y_BNG values for your points by multiplying the change per metre values you just derived and then adding the X_BNG and Y_BNG values of the first shot point (assuming the first shot point is to the west and south of the last shot point – **if your line orientation goes from north to south and/or east to west you'll need to work out change in that direction and do a subtraction**).

E.g., here X_BNG = (POINT_X * ΔX_BNG/m) + X_BNG_first_shot_point
Y_BNG = (POINT_X * ΔY_BNG/m) + Y_BNG_first_shot_point

SUM =(A2*$K$7)+$H$2

	A	B	C	D	E	F	G	H	I	J	K	L
1	POINT_X	POINT_Y	TWT_s	X_BNG				X_BNG	Y_BNG			
2	61666.11	-1118.9	-0.11189	$H$2			First SP	309307.5943	868540.4321			
3	61923.94	-1196.74	-0.11967				Last SP	429947.301	965373.5459			
4	62223.12	-1277.01	-0.1277									
5	62407.99	-1330.52	-0.13305									
6	62463.93	-1347.55	-0.13475					change X_BNG	change Y_BNG	total length	del X_BNG/m	del Y_BNG/m
7	62551.5	-1345.12	-0.13451					120639.7067	96833.1138	154695.1543	0.779854464	0.625960873
8	62639.06	-1306.2	-0.13062									

SUM =(A2*$L$7)+$I$2

	A	B	C	D	E	F	G	H	I	J	K	L
1	POINT_X	POINT_Y	TWT_s	X_BNG	Y_BNG			X_BNG	Y_BNG			
2	61666.11	-1118.9	-0.11189	357398.2	$I$2		First SP	309307.5943	868540.4321			
3	61923.94	-1196.74	-0.11967				Last SP	429947.301	965373.5459			
4	62223.12	-1277.01	-0.1277									
5	62407.99	-1330.52	-0.13305									
6	62463.93	-1347.55	-0.13475					change X_BNG	change Y_BNG	total length	del X_BNG/m	del Y_BNG/m
7	62551.5	-1345.12	-0.13451					120639.7067	96833.1138	154695.1543	0.779854464	0.625960873
8	62639.06	-1306.2	-0.13062									

Figure 6.9

6.12 You should now have 5 columns, which look like this:

	A	B	C	D	E
1	POINT_X	POINT_Y	TWT_s	X_BNG	Y_BNG
2	61666.11	-1118.9	-0.11189	357398.2	907141
3	61923.94	-1196.74	-0.11967	357599.3	907302.4
4	62223.12	-1277.01	-0.1277	357832.6	907489.7
5	62407.99	-1330.52	-0.13305	357976.7	907605.4
6	62463.93	-1347.55	-0.13475	358020.4	907640.4
7	62551.5	-1345.12	-0.13451	358088.7	907695.2
8	62639.06	-1306.2	-0.13062	358156.9	907750
9	62704.74	-1284.31	-0.12843	358208.2	907791.1

Figure 6.10

6.13 Check the values against your GIS project to convince yourself that these look correct – go back to your reference map and hover the cursor over the rough location of your interpretation and look at the coordinate values that are indicated (in example we are looking for coordinates near shot point 27).

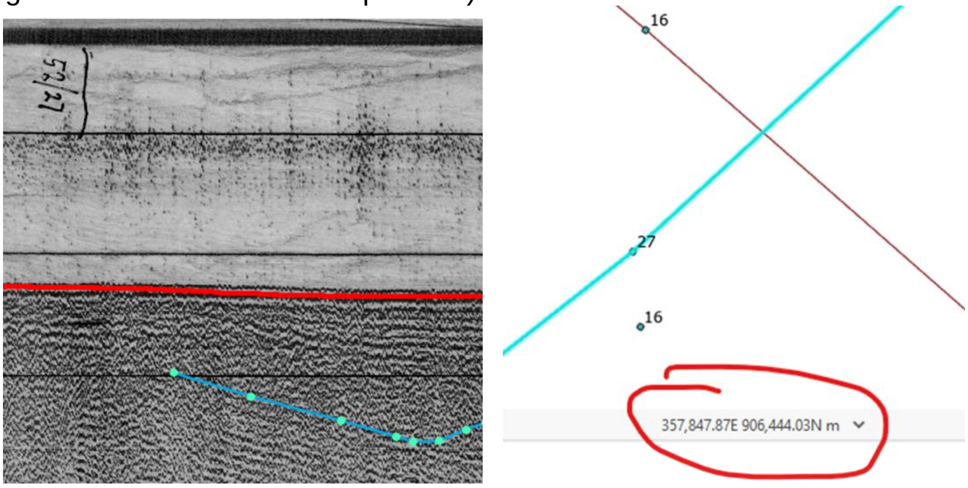


Figure 6.11

6.14 Now copy the 5 columns and paste as values only – either in a new sheet or the same one (you might want to preserve the first sheet with any formulas so you don't need to re-enter them for the next scanned profile). Remove the POINT_X and POINT_Y columns and rearrange so that your columns are in X_BNG, Y_BNG, TWT_s order, add a header mark at the beginning of the first cell e.g., > or # so that your excel sheet looks like this:

	A	B	C
1	>X_BNG	Y_BNG	TWT_s
2	357398.2	907141	-0.11189
3	357599.3	907302.4	-0.11967
4	357832.6	907489.7	-0.1277
5	357976.7	907605.4	-0.13305
6	358020.4	907640.4	-0.13475
7	358088.7	907695.2	-0.13451
8	358156.9	907750	-0.13062
9	358208.2	907791.1	-0.12843
10	358242.3	907818.6	-0.12697

Figure 6.12

You may also want to change the sign of your TWT values from negative to positive

6.15 This is now in X, Y, Z format in British National Grid, where the TWT_s is referenced to LAT. Save the file in a new folder within your Horizon_Interpretations folder called 'XYZ_files'– save as a text delimited file for use in other software, give an appropriate name that gives the horizon name and line name.

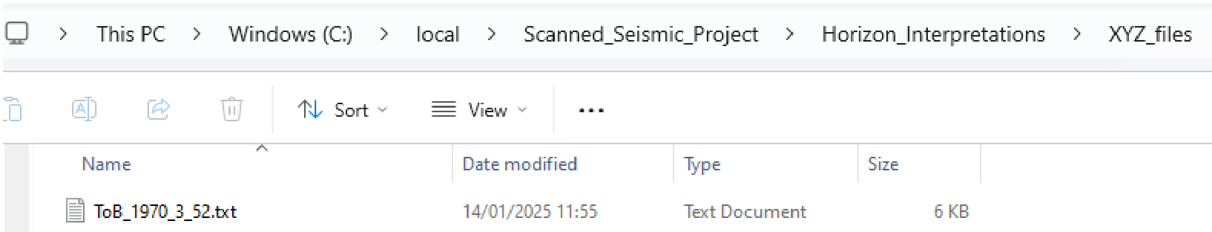


Figure 6.13

6.16 Ultimately, you will want to do this for all of the scans where you are interpreting the same horizon, then paste the additional X, Y, Z data all into one file (make sure you only have one header line), and then it can be used to grid a surface – and from there, if required, do a depth conversion using the bathymetry you have.

6.17 You can quality check the points you have extracted by importing them into your GIS project. Go to your Reference_Map and use the drop-down under 'Add Data' to select 'Add XY Point Data'. Use the folder icon next to the 'Input Table' field to navigate to and select the text file you've just created. Since this is just a quality check, you could leave the default output location and name, or you could change to a new folder such as 'QC_points' and add a '_p' suffix to the name. Select 'X_BNG' as the X field and 'Y_BNG' as the Y field, leave the Z field blank and change the Coordinate System to British National Grid. Click Run.

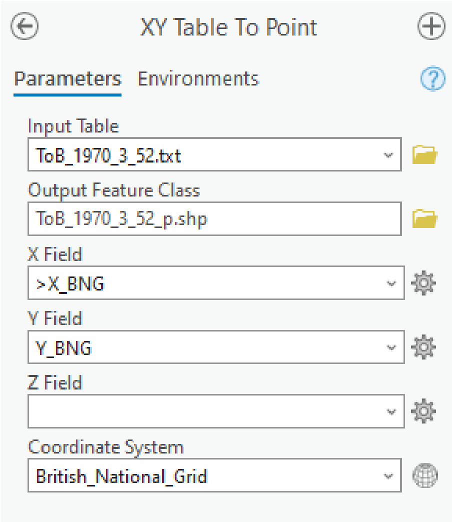


Figure 6.14

6.18 You should see your points added – note there is probably on offset from the seismic line scan (since it probably deviated from a straight line) – for the purposes and resolutions we're dealing with from these data this is not a serious issue/the offset is negligible.

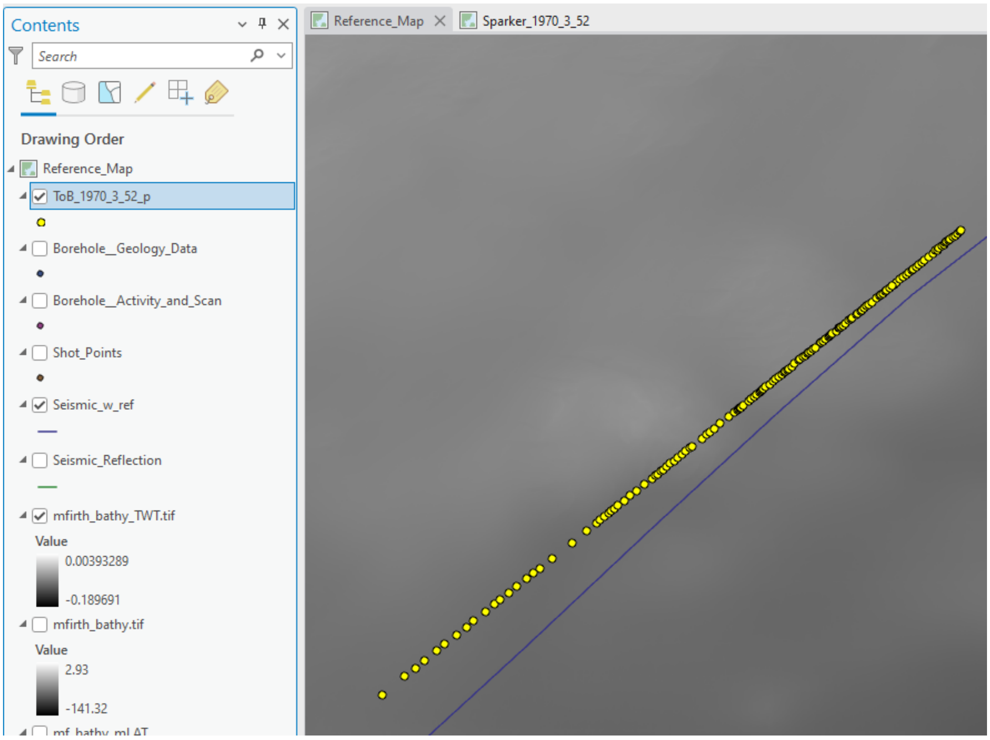


Figure 6.15

6.19 Right-click on the new points layer in the table of contents and go to 'Symbology'. Use the drop-down to select 'Unclassed Colors'. Use the drop-down next to 'Field' to select the 'TWT_s' field, you can play around with a colour scheme that suits you.

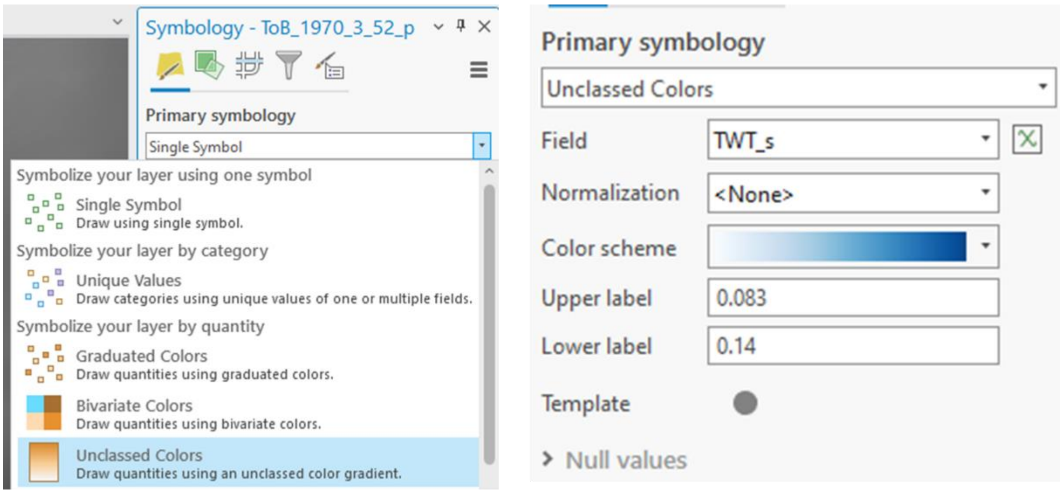


Figure 6.16

6.20 The points should now be coloured by their two-way-time value.

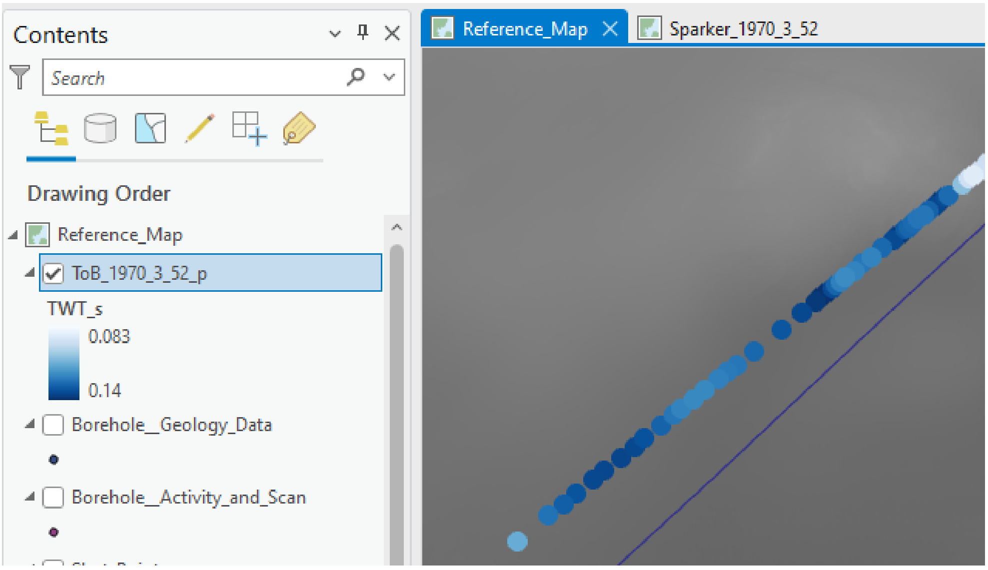


Figure 6.17

Now that you have an ArcGIS project set up you can keep adding maps for additional scans that you want to spatially reference and interpret. Ultimately, you will generate a set of XYZ text files for interpreted horizons – these could be imported as grids into another 3D data visualisation program for SEGY data such as Kingdom, Petrel, DUG etc.

Example Use

One goal of the BGS Marine Geoscience Program is to update and improve Quaternary Thickness maps for the UKCS, which were originally based on spot depths from boreholes with sufficient penetration depth and manual drawing of isopachs broadly guided by the early paper seismic records. Extracting additional stratigraphic geospatial information from the scanned legacy seismic data within a digital georeferenced environment enables capture of more detail with greater accuracy and could significantly improve the maps without acquiring new data.

To ensure that potential scope for using the legacy data is not overestimated, it is important that any user has a clear understanding of the limitations. The workflow outlined in this report addresses many of the issues associated with positioning of scanned legacy seismic data, however, other challenges remain. Primarily, the imaging quality of the original data. For older data (e.g., from 1970s cruises), and shallow water depth, there is insufficient suppression of the multiple to enable accurate interpretation (Figure 7.1).

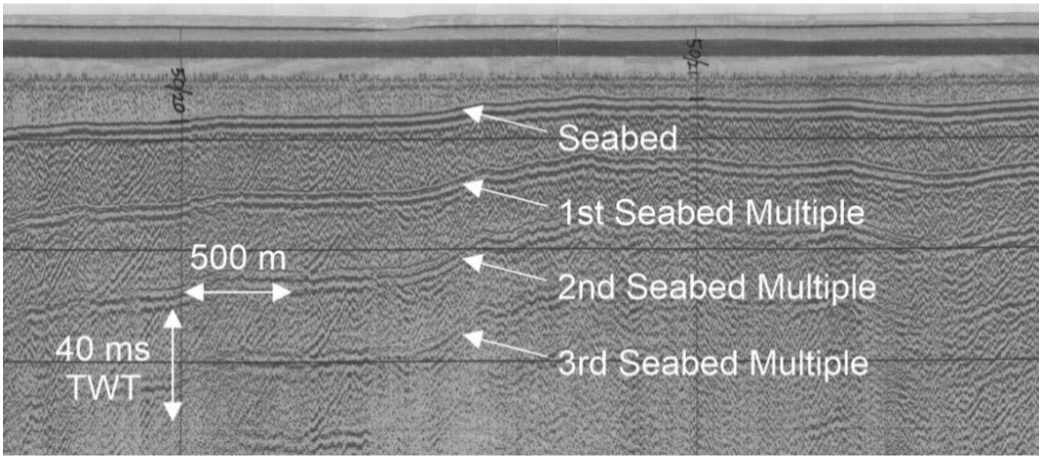


Figure 7.1. Example scanned seismic section from area of shallow water in the Moray Firth. Insufficient suppression of seismic artefacts, i.e., the seabed multiple, obscures real features.

Issues such as this that relate to the original seismic processing reduce the scope of what is achievable with the scanned data, and seismic lines must be carefully chosen to maximise reward for the effort to position them in space. Trawling the data for the best images is likely the most labour intensive aspect that a user of this report may face. Nevertheless, there are many scanned seismic lines that contain very valuable information to be extracted where the imaging is good (Figure 7.2).

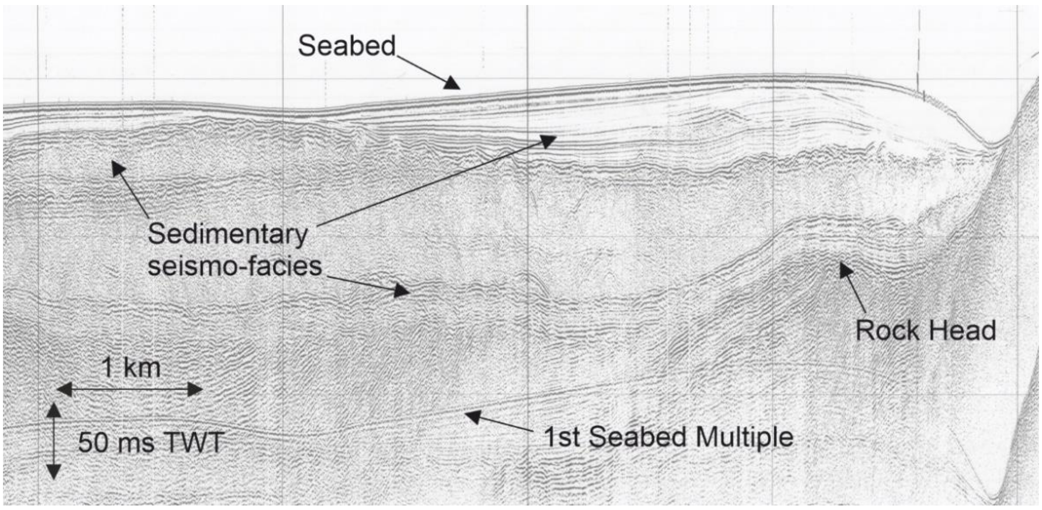


Figure 7.2. Example scanned seismic line from west of Skye, where there is good imaging of Quaternary sediments and the top of bedrock (Rock Head).

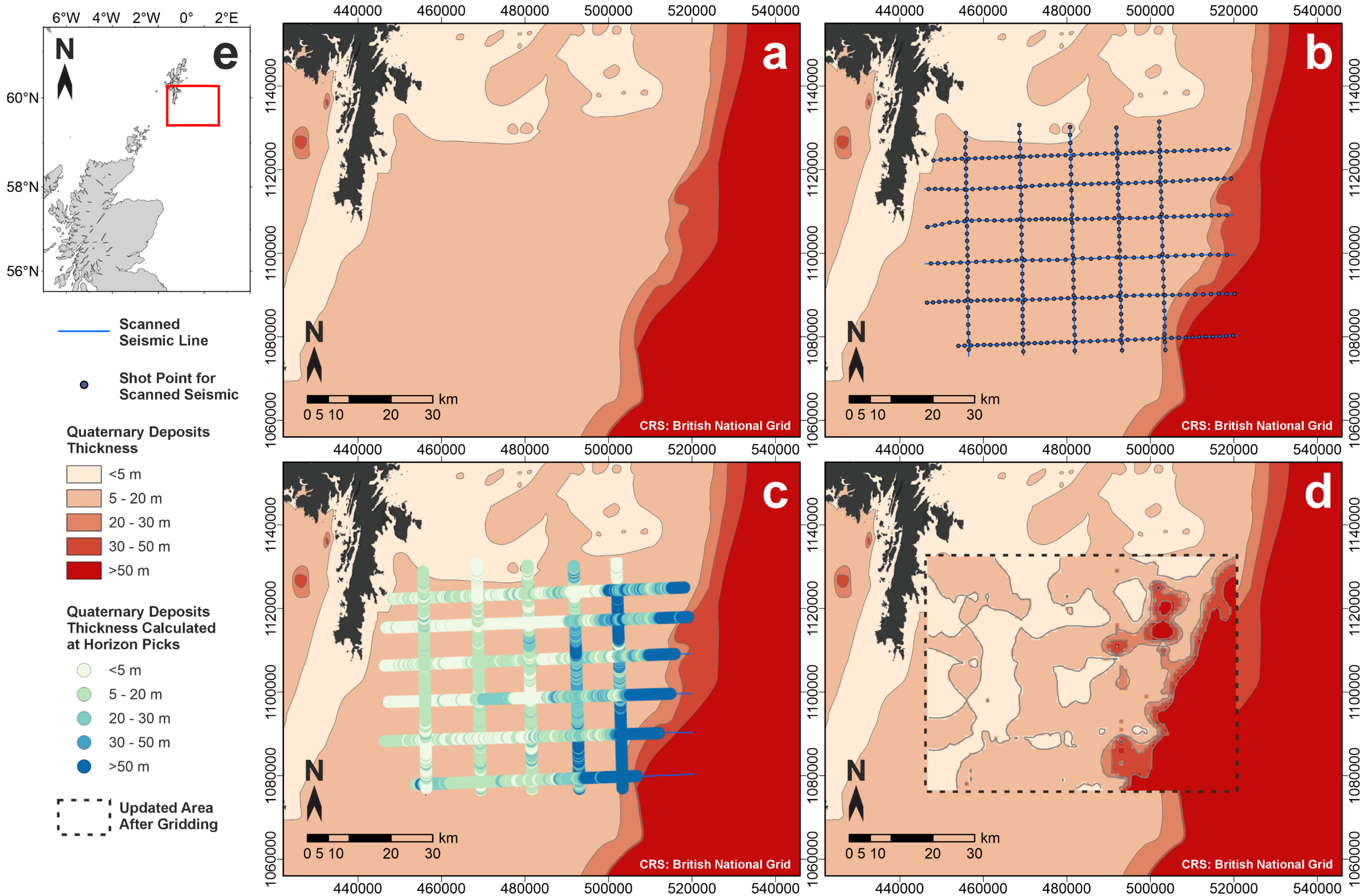


Figure 7.3. Using scanned legacy seismic data to update the BGS Offshore Quaternary Deposits map, southest of Shetland. (a) The existing BGS offshore Quaternary Deposits Thickness map. (b) Position of extracted scanned legacy seismic (sparker) records, and associated shot pots, used for interpretation. (c) Point data showing Quaternary thickness calculated at 1 m intervals along each seismic line where interpretation picks have been made. (d) Calculated thickness from interpretation gridded at 2 km spacing (inside the dashed lines) and contoured with the same intervals at the same intervals as the existing Quaternary Deposits Thickness map. (e) Regional location of the area depicted. CRS = Coordinate Reference System. Contains an extract from existing Quaternary thickness geological factor map produced as part of collaboration between BGS and The Crown Estate in 2014 BGS © UKRI. Contains OS data © Crown copyright and database right 2025.

Where there is sufficient coverage of scanned seismic with good image quality, applying the methodology may yield substantial new geological data for areas with gaps. Here, we show an example from southeast of Shetland, where scanned legacy sparker data consisting of five ~55 km long north-south lines and six ~70 km long west-east lines, span an area of ~4000 square kilometres. Spacing between the north-south lines is ~12 km, and spacing between the west-east lines is ~6.5 km (Figure 7.3). The data has been chosen based on good coverage, the regularly of spacing between the lines, and the imaging quality preserved in the scanned images. For this example, no bathymetry data was used, and the primary goal was to demonstrate the value of the data to improve resolution of BGS's offshore Quaternary Deposits Thickness (QDT) map. Therefore, the seabed and base Quaternary horizons were picked on each line (where possible), and the two-way-time difference calculated and converted to thickness in metres to provide a series of point location thickness values along each line, which could then be gridded.

Since the process for extracting the interpretation picks and accurately positioning them in 3-dimensional space is repetitive, we use a function written in python to generate output XYZ files, which could be compiled for gridding. The specifics of the python script and the inputs and outputs are detailed in the Appendix. The script is an example but could be adapted to the specific needs of a user.

Figure 7.3 shows the stages of the process by which the legacy data has been employed to improve BGS's QDT map (BGS 2022), which is largely derived from the original 1:1,000,000 scale UK offshore Quaternary map (Holmes et al., 1993). Part (a) shows the existing QDT map, where most of the region depicted is mapped as 5-20 m thickness; Part (b) shows the position of the selected legacy seismic data used and the associated shot points; Part (c) shows the thickness calculated by subtracting the interpreted base Quaternary horizon from the seabed horizon at regular points (picks have been resampled at a regular interval to allow easy subtraction – see the Appendix); Part (d) shows the result when the point data is gridded at a 2 km spacing and contoured using the same intervals as the existing QDT map; Part (e) shows the location. In this example, no borehole data was used directly, due to a data gap in currently available records. Other areas could be more thoroughly constrained using additional geotechnical data. However, the small subset of data used in this example, when compared to the number of scanned seismic lines available across the UKCS, demonstrates that significant detail can be added to the existing maps – compare Figure 7.3a and 7.3d.

Limitations

Maps generated using this methodology and the legacy data should be transparent about the nature of the data and the limitations.

Much of the legacy data was acquired (pre 1990s) before the adoption of highly accurate global positioning systems on survey vessels, such as Real-Time-Kinematics (RTK) for Global Navigation Satellite Systems (GNSS), so there may be inherent inaccuracies in the positioning of the shapefiles downloaded from the Geoindex. The accuracy of positioning the scanned data in the vertical plane (using this workflow) relies on sufficiently legible grid lines and labelling on the scanned image and assumes that where such information is available it has been recorded accurately during the original preparation of the paper records. The georeferencing process detailed in the workflow invites the potential for more human error. For seismic line geometries that have deviations from a straight line relative to the spacing between lines (excepting lines that have large-scale, obvious dog-legged geometries), it is unrealistic, or not possible, to expect to account for these deviations. Therefore, approximations will almost certainly be made for the position of interpretation picks, so that they are slightly offset from the true line position (see Figure 6.15). In addition, due to the irregularity of spacing between lines, and highly variable imaging quality, to generate grids, picks should be smoothed by spatial averaging prior to gridding, and the location of the point data should be provided with the final grids as in Figure 7.3c. This is to ensure that the constraints (or lack of) for areas between seismic lines is made clear.

Closing Remarks

Despite the associated limitations with legacy data/digitised paper records, these data have potentially far-reaching value. The example use above demonstrates the value for direct updates of existing maps without acquisition of new data. However, using the workflow in this report these data could be used to construct initial horizon grids or make a first-pass regional geological interpretation before further seismic data acquisition. Initial grids generated from the legacy data during a desk-based study, could be added to seismic interpretation software, where they can be better constrained by newly acquired SEG-Y datasets, or provide an initial guide to the interpreter.

The repository of open source scanned seismic, along with these instructions for how to extract useful geological information using software widely used by universities, expands the potential for the data to be used in student projects or blue-sky science, where there is no immediate commercial application. In addition, the workflow itself could also be utilised as a training resource. We invite potential users to engage with BGS to obtain mutual benefit from any outputs that result from application of the workflow or provide suggestions for improvement.

References

BRITISH GEOLOGICAL SURVEY. (2022). Quaternary deposits thickness across the UK Continental Shelf (2014 Version). NERC EDS National Geoscience Data Centre. (Dataset). https://doi.org/10.5285/0cc60652-c02c-4931-b5bf-def9299b68f2

HOLMES, R., JEFFREY, D.H., RUCKLEY, N.A., AND WINGFIELD, R.T.R. 1993. QUATERNARY GEOLOGY AROUND THE UNITED KINGDON (NORTH SHEET). 1:1 000 000. (EDINBURGH: BRITISH GEOLOGICAL SURVEY).

THE BGS OFFSHORE GEOINDEX (HTTPS://WWW.BGS.AC.UK/MAP-VIEWERS/GEOINDEX-OFFSHORE/)

THE ADMIRALTY MARINE DATA PORTAL (HTTPS://DATAHUB.ADMIRALTY.CO.UK/PORTAL/APPS/SITES/#/MARINE-DATA-PORTAL)

Appendix

Below is an example script for a python function, coded in python version 3.12.4, and using the numpy and pandas modules. It's important to emphasize that this is an example, which could be better refined, and/or adapted and updated by a potential user of this report to suit their specific requirements. See section below for the format of inputs required for the code to run successfully.

CODE

```
#! python3
# extract_thickness_metres.py

import numpy as np
import pandas as pd


def calculate_horizon_depth_mbsf(
    seismic_line,
    seabed_csv,
    horizon_csv,
    first_sp_x,
    first_sp_y,
    last_sp_x,
    last_sp_y,
    fudge_factor=10,
    s_or_ms="ms",
    first_sp_relative_position="sw",
    interp_x_uses="x",
    seis_velocity_m_per_s=1700,
):
    """
    This script is an example to show how conversion of the points
    data exported from interpretations made in ArcGIS Pro on scanned
    seismic can be automated. To address the specific needs of the
    user, the script will need to be editted.

    The inputs to the function should be as follows (and see
    example use of function below):
    seismic_line = a string used to generate the output file name
    seabed_csv = path to file for a two column csv file with the
    POINT_X and POINT_Y values for a seabed pick
    horizon_csv = path to file for a two column csv file with the
    POINT_X and POINT_Y values for a horizon pick
    first_sp_x = the easting value for the first shot point along
    the line for which the data is being converted
    first_sp_y = the northing value for the first shot point along
    the line for which the data is being converted
    last_sp_x = the easting value for the last shot point along
    the line for which the data is being converted
    last_sp_y = the northing value for the last shot point along
    the line for which the data is being converted
    fudge_factor = the multiplier used to preserve the vertical
    exaggeration of the scanned seismic in ArcGIS Pro
```

```
    s_or_ms = either 's' or 'ms' depending on whether the values
    for the interpretation represent time in seconds or
    milliseconds
    first_sp_relative_position = 'sw', 'se', 'nw', or 'ne' - the
    position of the first shot point (used in the conversion)
    relative to the rest of the seismic line
    interp_x_uses = 'x' or 'y' - in the georeferencing, was the
    x (easting) values used or the y (northing) values used
    seis_velocity_m_per_s = value for velocity to be used in
    depth conversion in metres per second

    """
    # users specifies whether the twt values are in seconds ('s') or
    # milliseconds ('ms') in the input, along with the fudge factor used
    # e.g., x10 to preserve vertical exaggeration in arc for georeferenced
    # scan. The multiplier of 2 accounts for two-way-time
    if s_or_ms == "s":
        time_divider = 2 * 1 * fudge_factor
    elif s_or_ms == "ms":
        time_divider = 2 * 1000 * fudge_factor

    # load interpreted seabed data from exported csv file
    seabed = pd.read_csv(seabed_csv, sep=",")

    # load interpreted horizon data from exported csv file
    horizon = pd.read_csv(horizon_csv, sep=",")

    # if the seabed and horizon picks were made up of multiple lines within the
    # feature in arc, they may not be ordered correctly, but they can be sorted
    # into ascending order
    seabed = seabed.sort_values(by=["POINT_X"])
    horizon = horizon.sort_values(by=["POINT_X"])

    # resample the seabed and horizon at regular points to enable direct
    # calculation between seabed and horizon. First check whether the
    # x (easting) values or y (northing) values where used to georeference the
    # scan
    if interp_x_uses == "x":
        min_x_val = np.min((first_sp_x, last_sp_x))
        max_x_val = np.max((first_sp_x, last_sp_x))

    elif interp_x_uses == "y":
        min_x_val = np.min((first_sp_y, last_sp_y))
        max_x_val = np.max((first_sp_y, last_sp_y))

    # create an array of values where to resample at (as integer values)
    sample_x_vals = np.arange(
        (float(round(min_x_val, 0) + 1)), float((round(max_x_val, 0))), 1
    )

    # use an interpolation to resample the picks - note that this will generate
    # points where there was no original data if there are gaps in the pick.
    # Gaps may relate to where the horizon pinches out at the seabed (as in
```

```
    # this example), but for other cases, it may be nessary to split the
    # interpretation csv file to avoid unwanted interpolation

    seabed_resample = np.column_stack(
        (sample_x_vals, (np.interp(sample_x_vals, seabed.POINT_X, seabed.POINT_Y)))
    )

    horizon_resample = np.column_stack(
        (sample_x_vals, (np.interp(sample_x_vals, horizon.POINT_X, horizon.POINT_Y)))
    )

    # get the change in the easting (as a positive value)
    dx = abs(last_sp_x - first_sp_x)

    # get the change in the northing (as a positive value)
    dy = abs(last_sp_y - first_sp_y)

    # get the total distance along the seismic profile
    # (assumes a straight line)
    total_dist_along_line = np.sqrt((dx**2) + (dy**2))

    # calculate the true x (easting) and y (northing) values for the
    # interpretation this depends on the relative position of the
    # first shot point (sw, se, nw, or ne) - as specified in the
    # function input
    if first_sp_relative_position == "sw":
        # where the first shot point is in the south west, both x and y increase
        true_x = (
            (sample_x_vals - np.min(sample_x_vals)) * (dx / total_dist_along_line)
        ) + first_sp_x

        true_y = (
            (sample_x_vals - np.min(sample_x_vals)) * (dy / total_dist_along_line)
        ) + first_sp_y

    elif first_sp_relative_position == "se":
        # where the first shot point is in the south east, x decreases whilst y
        # increases
        true_x = first_sp_x - (
            (sample_x_vals - np.min(sample_x_vals)) * (dx / total_dist_along_line)
        )

        true_y = (
            (sample_x_vals - np.min(sample_x_vals)) * (dy / total_dist_along_line)
        ) + first_sp_y

    elif first_sp_relative_position == "nw":
        # where the first shot point is in the south east, x increases whilst y
        # decreases
        true_x = (
            (sample_x_vals - np.min(sample_x_vals)) * (dx / total_dist_along_line)
        ) + first_sp_x
```

```python
        true_y = first_sp_y - (
            (sample_x_vals - np.min(sample_x_vals)) * (dy / total_dist_along_line)
        )

    elif first_sp_relative_position == "ne":
        # where the first shot point is in the south east, both x abd y decrease
        true_x = first_sp_x - (
            (sample_x_vals - np.min(sample_x_vals)) * (dx / total_dist_along_line)
        )

        true_y = first_sp_y - (
            (sample_x_vals - np.min(sample_x_vals)) * (dy / total_dist_along_line)
        )

    # calculate the depth of the horizon below seabed
    depth_mbsf = (
        (abs(horizon_resample[:, 1]) - abs(seabed_resample[:, 1])) / time_divider
    ) * seis_velocity_m_per_s

    # in this case, the interpolation will have generated horizon points shallower
    # than the seabed, indicating where the horizon has pinched to the seabed
    # therefore, we want to define these areas as 0 depth below seabed
    depth_mbsf[depth_mbsf < 0] = 0

    # compile the calulcated data into a dataframe ready for output (note in this
    # example, the coordinate reference system is British National Grid, so the
    # x and y fields are labelled appropriately)
    output = pd.DataFrame({"X_BNG": true_x, "Y_BNG": true_y, "depth_mbsf": depth_mbsf})

    # export the output to a csv file

    # first generate appropriate name
    outfile = "%s_horizon_mbsf.csv" % seismic_line

    # send data to file
    output.to_csv(outfile, float_format="%.4f", sep=",", index=False, header=True)


""" Example use of function """
calculate_horizon_depth_mbsf(
    seismic_line="line_1",
    seabed_csv="./interps_exported_from_arc/line_1_seabed.csv",
    horizon_csv="./interps_exported_from_arc/line_1_horizon.csv",
    first_sp_x=448042.37707,
    first_sp_y=1122202.8878,
    last_sp_x=518531.69499,
    last_sp_y=1124974.14703,
    fudge_factor=10,
    s_or_ms="ms",
    first_sp_relative_position="sw",
    interp_x_uses="x",
    seis_velocity_m_per_s=1700,
)
```

EXAMPLE INPUTS FOR CODE

The example code above requires two file inputs in the form of csv files, which can be generated from picks made by following the first 4 steps in section 6. There should be one file for the seabed, and one for a deeper horizon that has been interpreted. The conversion of the POINT_Y field to depth is performed within the code. See comments within code above for explanation of user-specified function inputs.

	A	B	C
1	POINT_X	POINT_Y	
2	447793.3	-1549.15	
3	447912.2	-1629.5	
4	448082.6	-1610.21	
5	448182.2	-1655.21	
6	448307.6	-1696.99	

	A	B	C
1	POINT_X	POINT_Y	
2	514968.2	-2623.71	
3	515161.6	-2547.88	
4	515256.4	-2547.88	
5	515385.3	-2654.05	
6	515586.2	-2824.66	

Figure A1. Format of csv files required for code. (Seabed file is on the left, horizon file is on the right).

The POINT_X fields do not need to match, as long as the coordinate format is the same – as scripted above, the code will sort the values for POINT_X and POINT_Y based on ascending order for POINT_X and resample at integer values in POINT_X, so that the result matches exactly, and a straightforward subtraction performed.

As per the specifics of the script above, the input csv files are stored in a 'interps_exported_from_arc' directory and the script should be run from one directory level up:

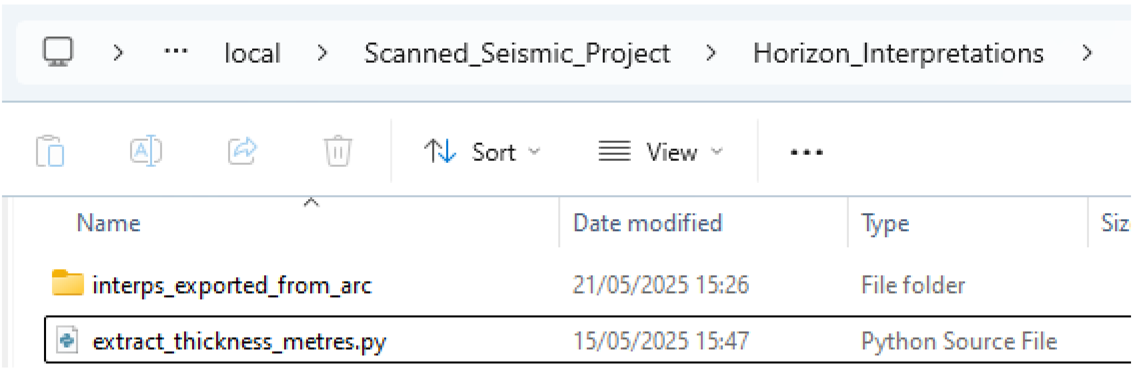
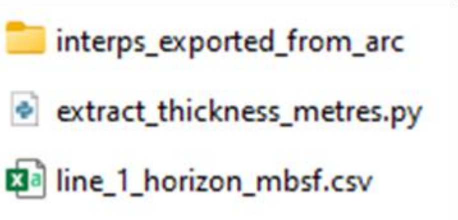


Figure A2.

At the base of the script above there is an example use of the function, showing the user defined inputs, for a southwest to northeast trending seismic profile where the picks have been extracted. Running the function will generate a three-column csv file, as shown in Figure A3, stored in the same directory as the code.



	A	B	C
1	X_BNG	Y_BNG	depth_mbsf
2	448042.4	1122203	3.4863
3	448043.4	1122203	3.488
4	448044.4	1122203	3.4896
5	448045.4	1122203	3.4913
6	448046.4	1122203	3.4929
7	448047.4	1122203	3.4946

Figure A3.

The function can be re-run for each line where there are picks to be processed, and the resulting csv files compiled into a XYZ file, which can be imported to ArcGIS Pro, or used to generate a gridded surface.